‘DØ Run 2b Silicon Tracker’ An overview

Director’s Baseline Review
(Temple Review)
April 16-18, 2002

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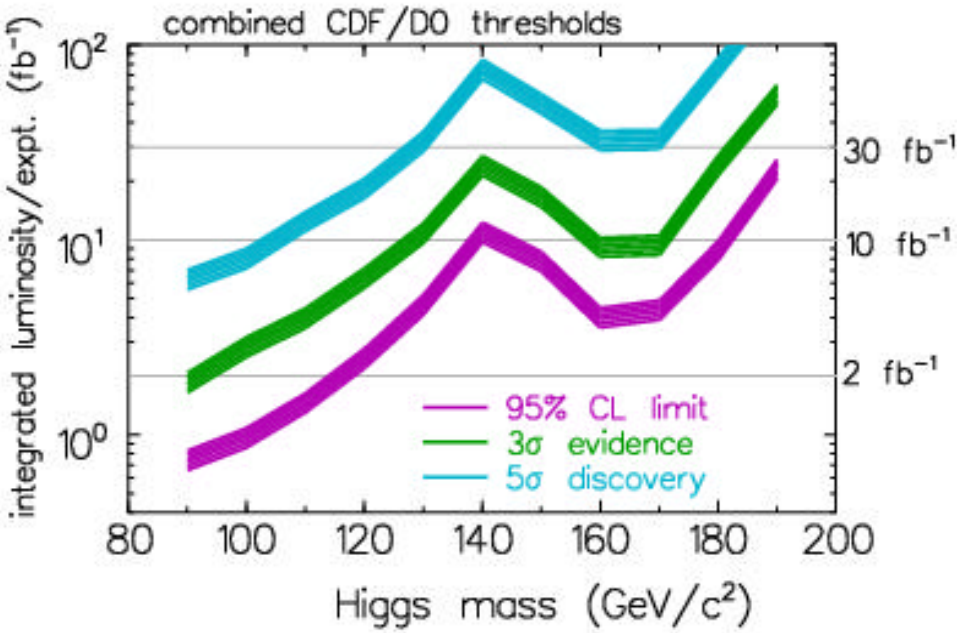
Fermilab

For the Run 2b Silicon Group

Run 2b

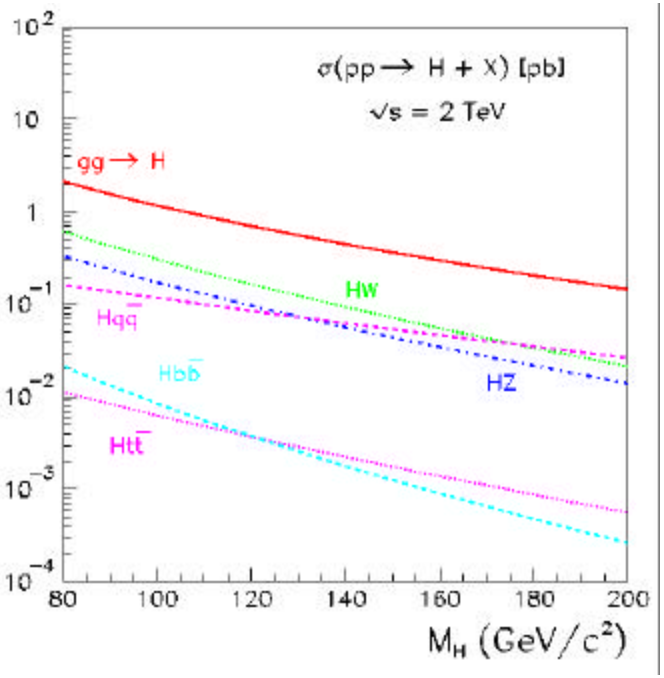
- Although we just built a major silicon detector, construction of a new silicon detector is planned
- Current silicon detector designed for ~ 2 fb^{-1}; will most likely survive 4-5 fb^{-1}
  - The most appropriate rad-hard technology used at that time
- Laboratory:
  - Supports extended running to ~ 15 fb^{-1} / exp
    - » Unique window of opportunity for Fermilab to be the sole laboratory with possibility to find the Higgs boson
  - Asked both collaborations to study options for replacing Si detectors
    - » Choice of exp's is full replacement
  - Suggested a time scale and asked for submission of TDR by fall '01
- Field of High Energy Physics
  - Higgs search is highest priority of the laboratory and perhaps the field

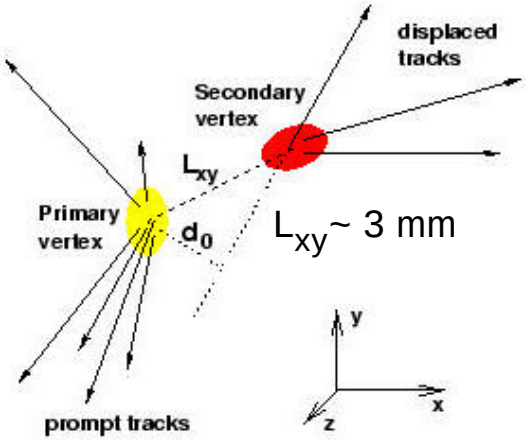


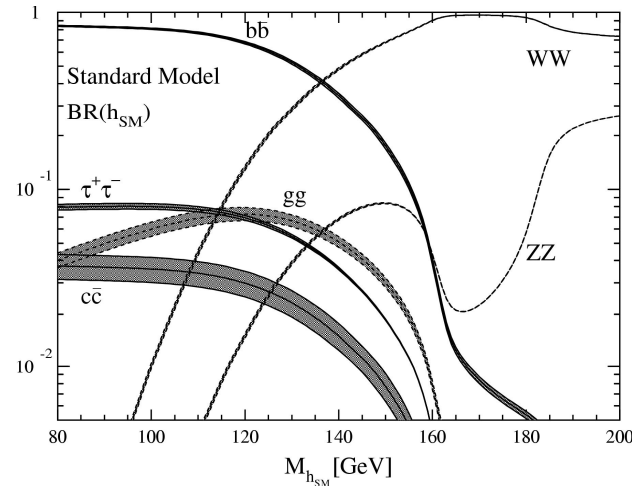
- LHC: turn on of LHC sets clear end date for window of opportunity

Higgs Boson

- Production
  - Dominant production channel gg → H
    - » Overwhelmed by background
  - Observable production channel qq → WH, ZH
    - » Lepton from W/Z provides trigger
- Decay
  - H coupling proportional to mass
  - Dominant decay to bbar
- Requirements
  - Excellent b-tagging efficiency
    - » ε_b > ~65 % per jet at mistag rate < ~1%
  - Robust silicon tracker
    - » lean but with adequate redundancy

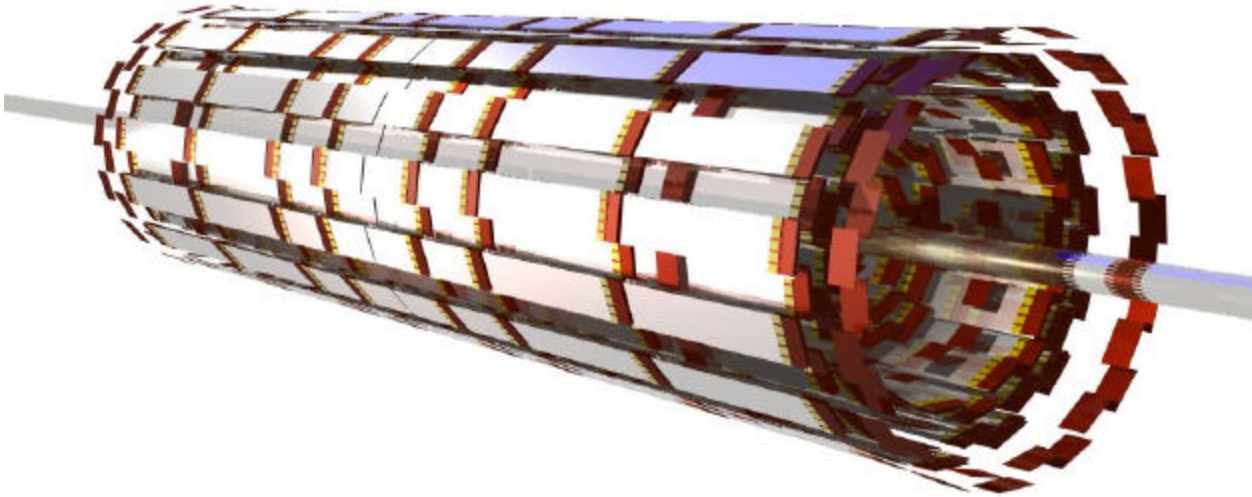






Outline

- Design considerations
  - Boundary conditions
    - » Space
    - » DAQ constraint
    - » Silicon track trigger
    - » Radiation damage
- Brief overview of proposed detector
- Anticipated performance
- Project overview
  - Organization
  - Cost: M&S
  - Schedule
  - Resources
- Conclusion

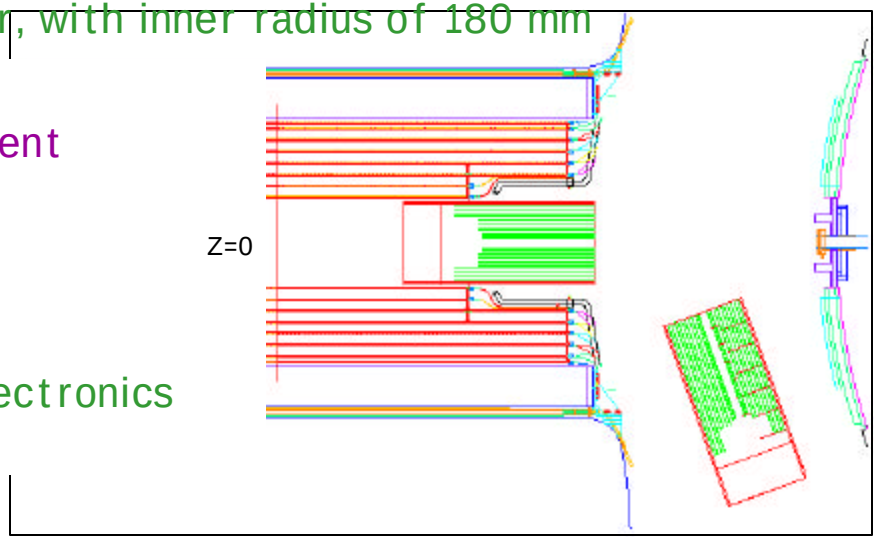


Design Considerations

- Do not compromise on the performance of the Run2a silicon tracker
- Choose design adequate to achieve physics goals but do not over-design (no 90-degree stereo),
- Provide stand-alone tracking up to $|\eta| < 2.0$
  - Fiber tracker has full coverage only up to $|\eta| < 1.6$
- Modular design, minimize the number of different elements
- Use established technologies
  - Use single sided silicon only
- Due to harsh radiation environment, divide tracker in two radial groups:
  - Inner layers
    - » Design to withstand integrated luminosity of 15 fb^{-1}, with adequate margin
    - » Provide path for possible replacement of innermost layers
  - Outer layers
    - » Design to last a long time

Boundary Conditions

- Spatial
  - Installation within existing fiber tracker, with inner radius of 180 mm
  - Installation in collision hall
    - » Tracker will be built in two independent half-modules, split at z=0



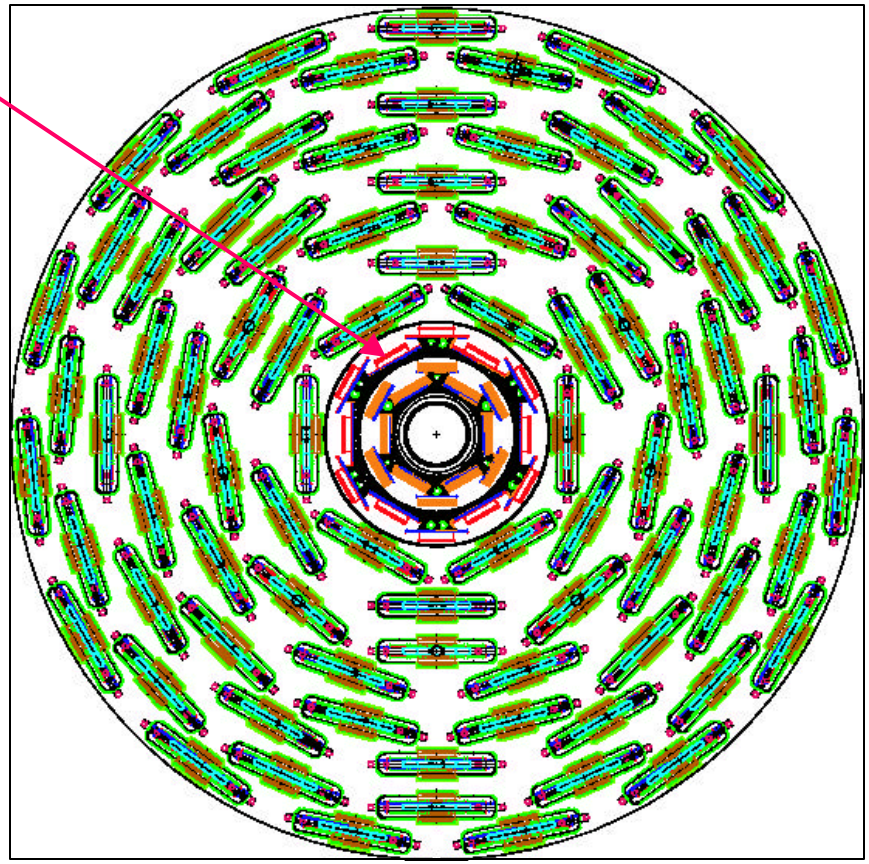
- Data Acquisition
  - Retain all of the downstream readout electronics
  - Re-use current cable plant
    - » allows for ~912 readout modules
  - Total number of readout modules cannot exceed 912
- Silicon Track Trigger
  - Respect 6-fold symmetry
- Radiation Damage
  - Limit V_{depl} to ~700V after 15 fb^{-1}, and minimize I_{leak} for innermost radii
  - Requires silicon operating temperature of –10° C, off-board electronics for innermost layer

Radiation Damage

- To be filled out
- Give operating temperature of silicon for each layer

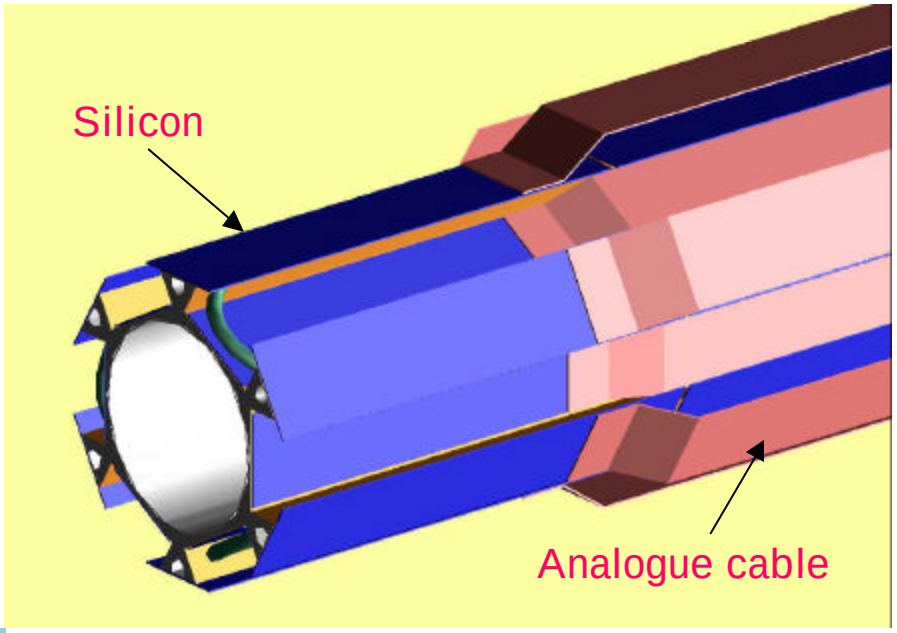
Basic Layout

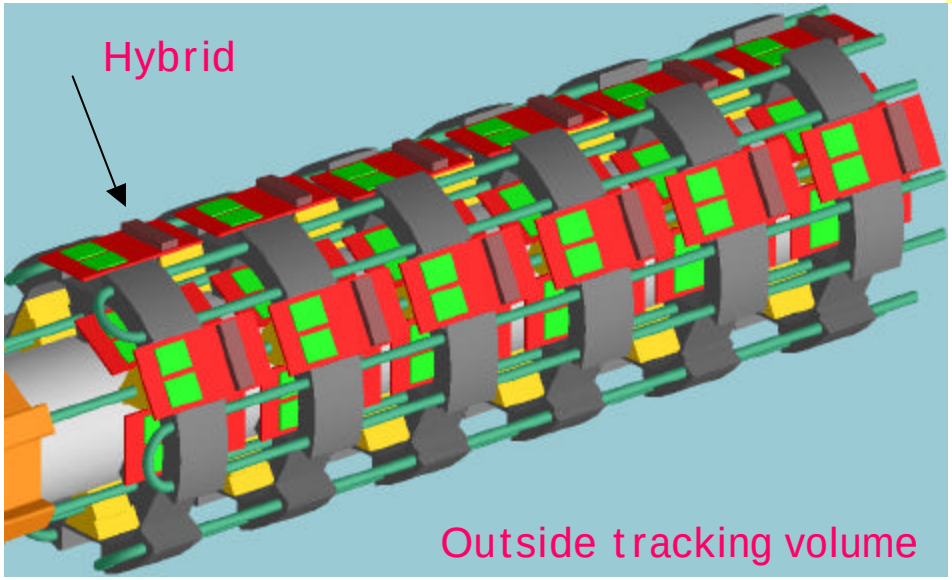
- Six layer silicon tracker, divided in two radial groups
  - Inner layers: Layers 0 and 1
    - » Axial readout only
    - » Mounted on integrated support
    - » Assembled into one unit
    - » Designed for V_{bias} up to 700 V
  - Outer layers: Layers 2-5
    - » Axial and stereo readout
    - » Stave support structure
    - » Designed for V_{bias} up to 300 V
- Employ single sided silicon only, 3 sensor types
  - 2-chip wide for Layer 0
  - 3-chip wide for Layer 1
  - 5-chip wide for Layers 2-5
- No element supported from the beampipe
- Drilled Be Beampipe with ID of 0.96", 500μm wall thickness



Layer 0

- Support Structure
  - 12-fold crenellated geometry
  - carbon fiber support
  - possible use of pyrolitic graphite
  - sensors cooled to T=-10 ^{o}C
  - R_{in} = 18.5 mm

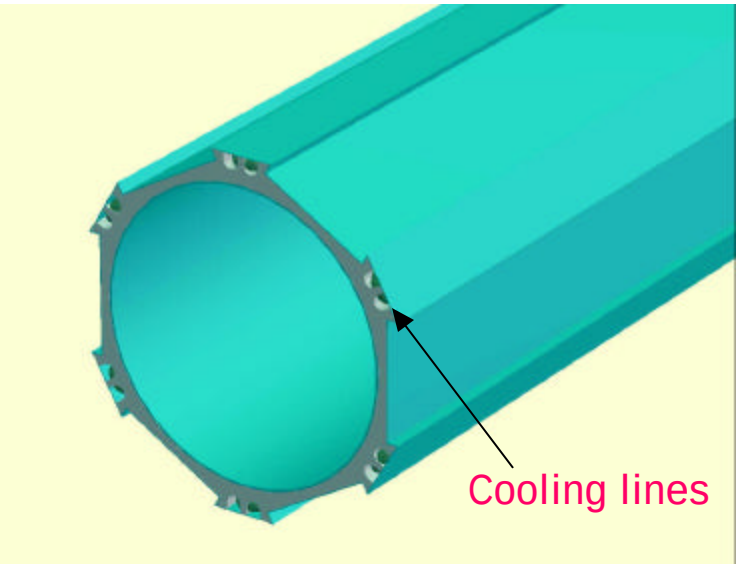


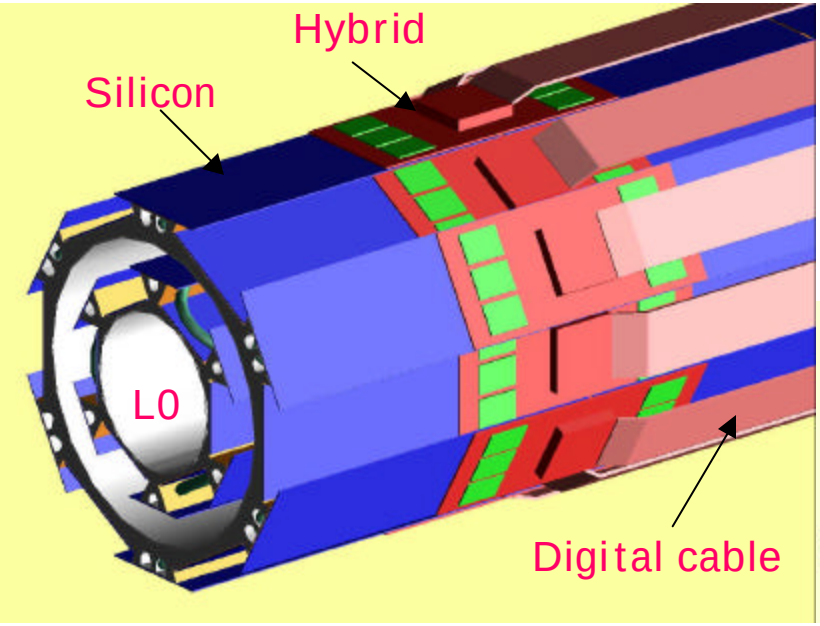


- Assembly
  - 2-chip wide sensors
  - 25 mm pitch, 50 mm readout
  - Analogue cables for readout
  - Hybrids off-board
  - Staggered in z for 6 readouts per end per phi-sector
- Space is extremely tight !

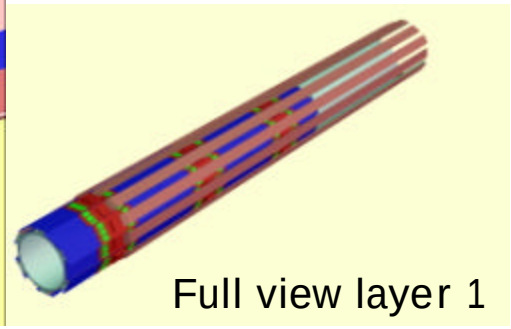
Layer 1

- Support Structure
  - 12-fold castellated geometry
  - carbon fiber support
  - Integrated cooling
  - sensors cooled to T=-5 ^{o}C
  - R_{in} = 34.8 mm



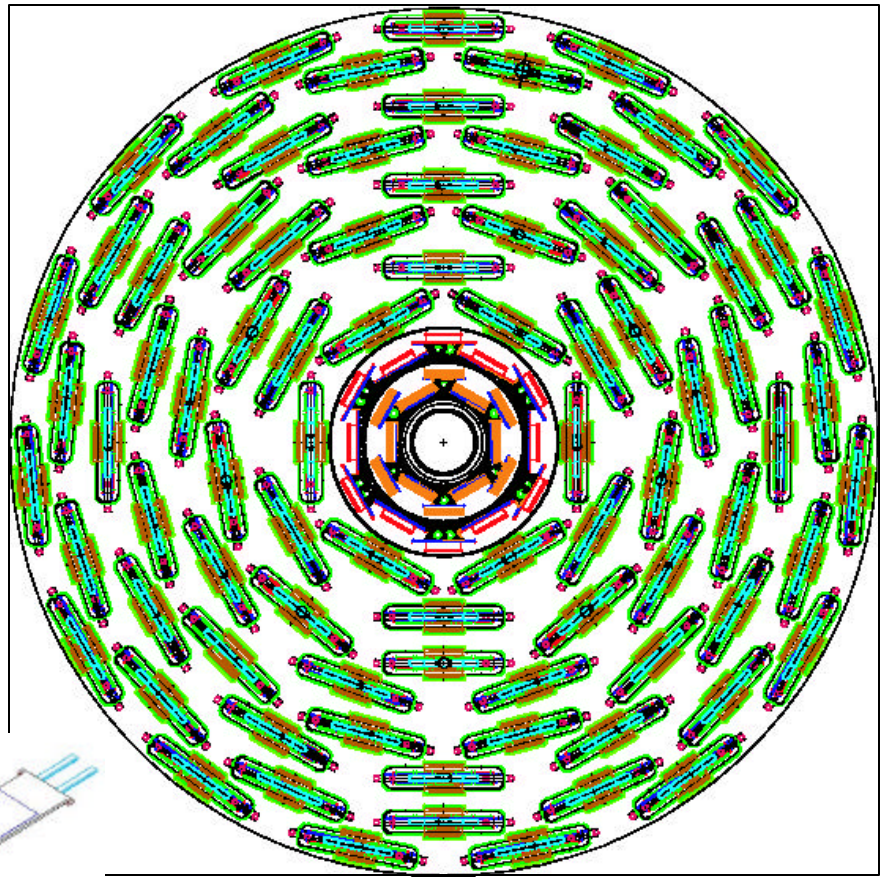


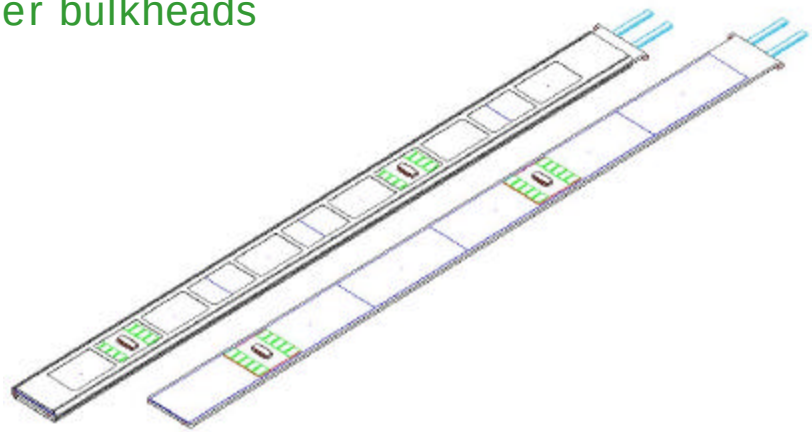
- Assembly
  - 3-chip wide sensors, 58 μm pitch, axial readout
  - Hybrids on-board
  - 6-chip double-ended hybrid readout



Layers 2-5

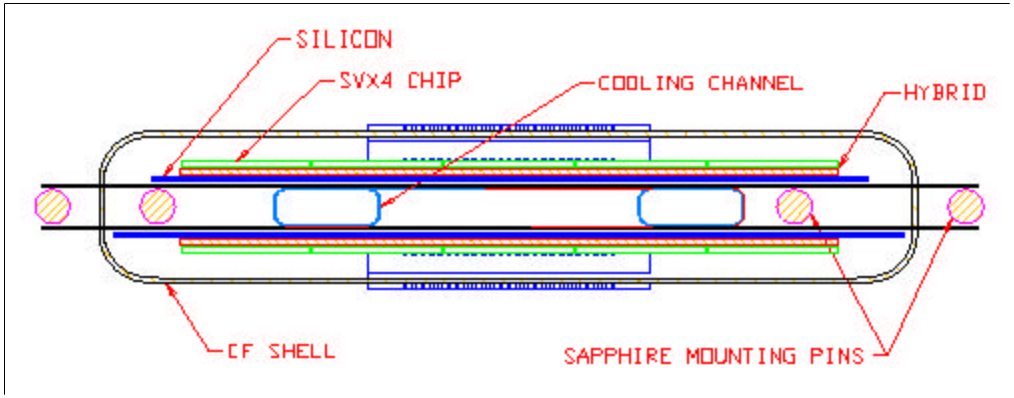
- 12, 18, 24 and 30-fold geometry
- All layers:
  - Use the same sensor, 5-chip wide sensor, 30 μm pitch, 60 μm readout
  - Hybrids on-board
  - 10-chip hybrid readout
  - Stereo and axial readout
  - Stereo angle obtained by rotating sensor
- Support
  - Modules are assembled into staves
  - Staves are positioned with carbon-fiber bulkheads

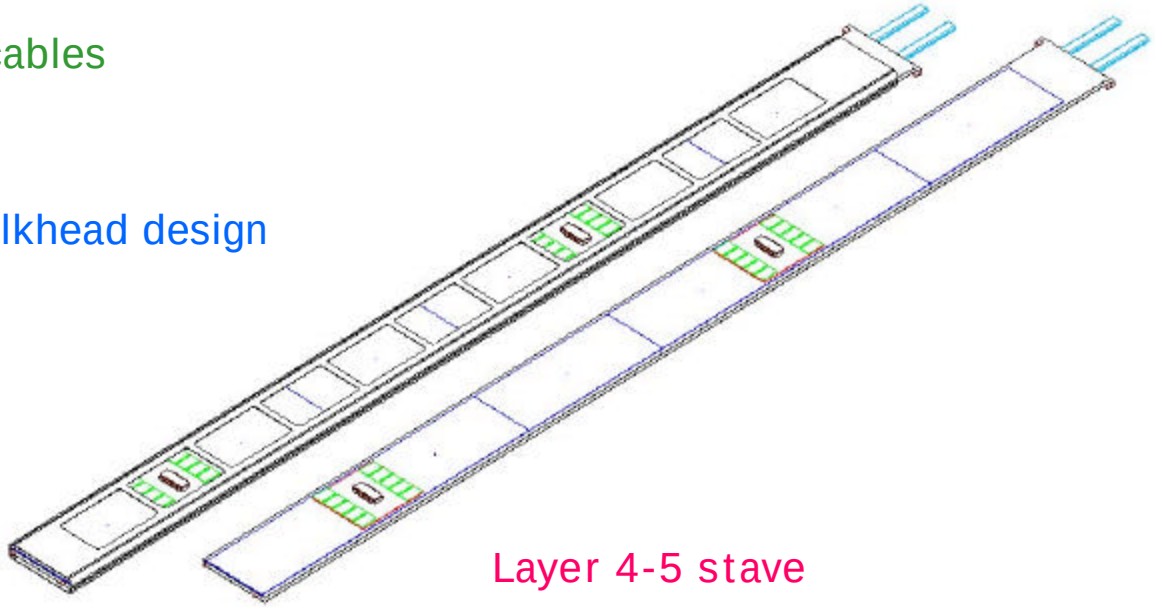




Stave Structure

- Stave is doublet structure of four readout modules
  - Two layers of silicon
    - » Axial and stereo
    - » Two readout modules each
  - separated by cooling lines
  - Total of 168 staves
- Stave has carbon fiber cover
  - Protect wirebonds
  - Provide path for digital cables
- Staves are mounted in end carbon fiber bulkheads
- Cooling manifold similar to bulkhead design

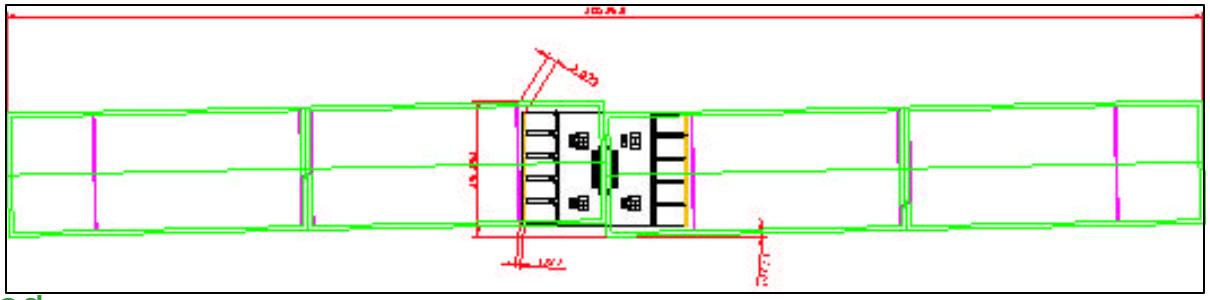




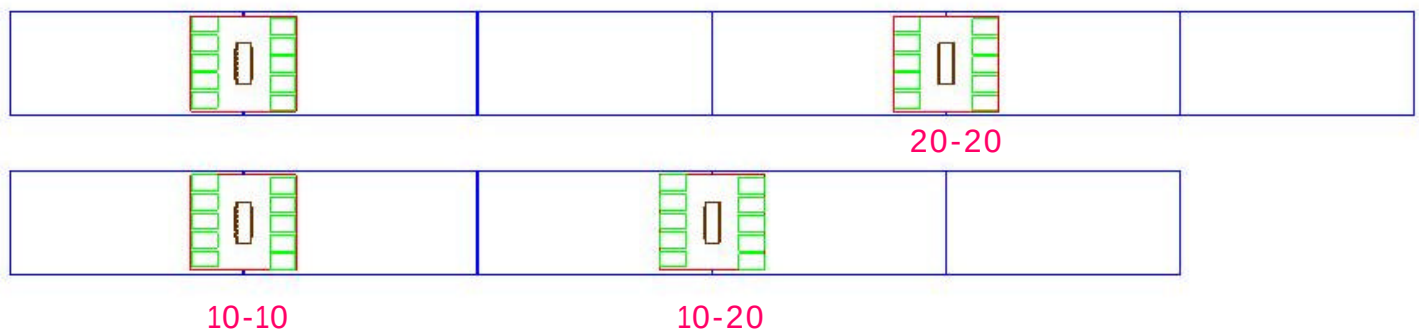
Layer 4-5 stave

Outer Layer Readout Modules

- Staves are assembled from readout modules
- Readout modules:
  - 6 types
    - » 10-10 (axial, stereo)
    - » 10-20 (axial, stereo)
    - » 20-20 (axial, stereo)
  - Stereo angle determined by mechanical constraints
    - » 10cm readout: $\alpha = 2.5^{o}$
    - » 20cm readout: $\alpha = 1.25^{o}$
  - Ganged sensors will have traces aligned



- Module configuration



Layer 4-5

Layer 2-3

- Each readout module serviced by double-ended hybrid
  - Each hybrid has two independent readout segments

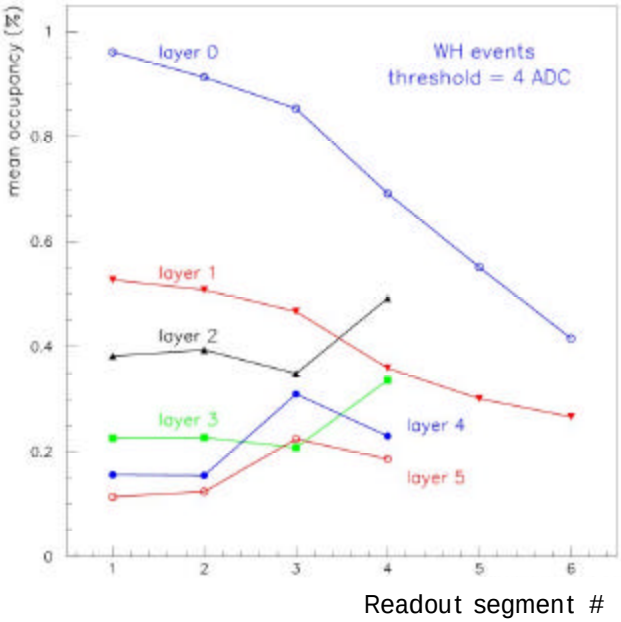
Longitudinal Segmentation

- Designed the detector to have uniform coverage in pseudorapidity
  - Layers 0/1: 6 sensors per half-module; sensor length 79.4 mm
  - Layers 2/3: stave populated by 5 sensors only; sensor length 100 mm
    - » reduction of sensor count by 120 sensors
  - Layers 4/5: stave populated by 6 sensors; sensor length 100 mm

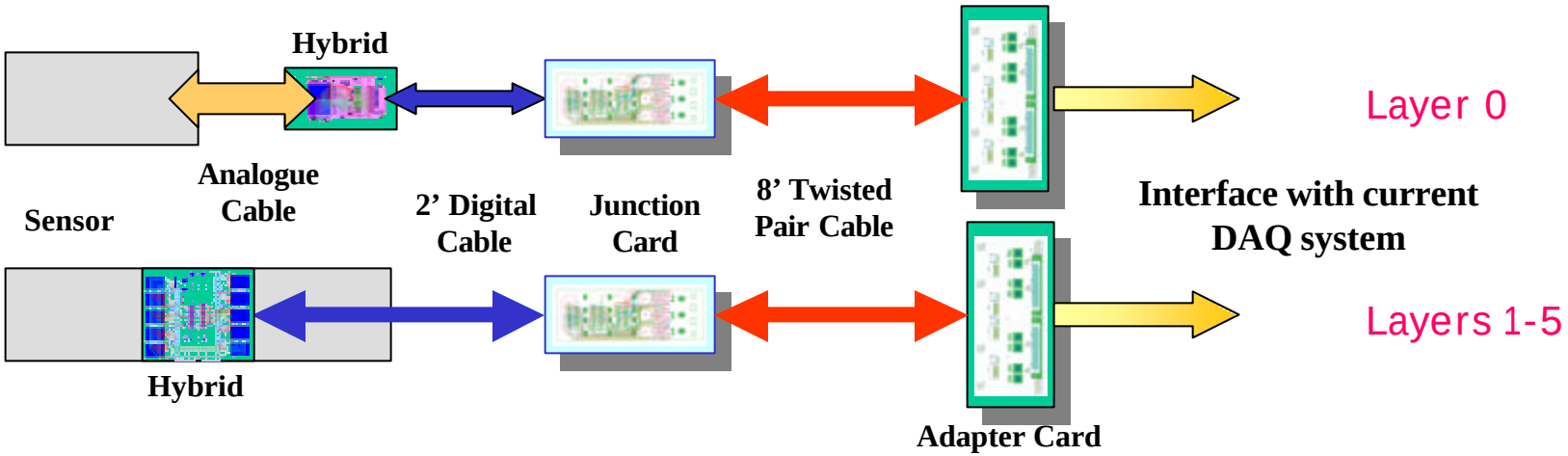
Z=0 Z (mm)

	0		40		80		120		160		200		240		280		320		360		400		440		480		520		560		600
Layer 0				S				S				S				S				S				S							
Layer 1				1/2D	1/2D							1/2D	1/2D							1/2D	1/2D										
Layer 2					1/2D	1/2D									1/2D	1/2D															
Layer 3					1/2D	1/2D									1/2D	1/2D															
Layer 4					1/2D	1/2D														1/2D	1/2D										
Layer 5					1/2D	1/2D														1/2D	1/2D										

- Longitudinal segmentation
  - Determined by
    - » Number of allowed readout cables
    - » Occupancy, cluster sharing
    - » Configuration
      - L0, L1: each sensor readout
      - L2, L3: 10-10-10-20 readout
      - L4, L5: 10-10-20-20 readout
- Hybrids are all double-ended
  - Services two readout segments



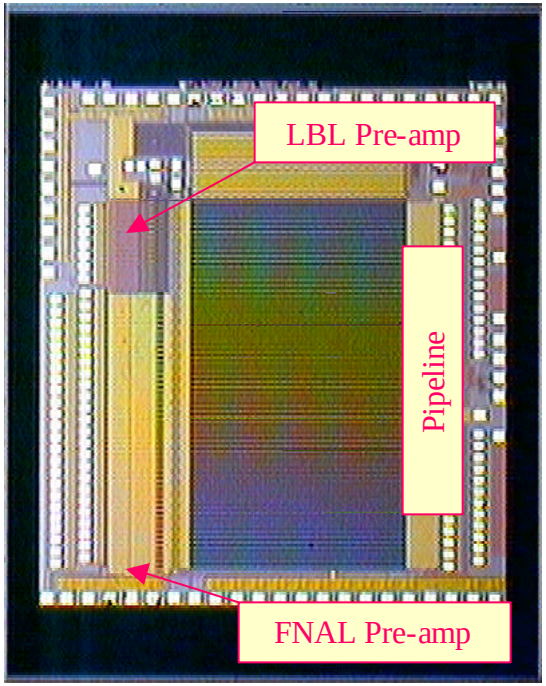
Readout Schematics



- SVX4 chip employed in SVX2 readout mode to readout signals
- Layer 0:
  - Due to cooling requirements, hybrids off-board
    - » Fine pitch flexible cables to bring analogue signals out of tracking volume
- Layers 1-5
  - Hybrids mounted on silicon
  - Digital cable connects to hybrid
    - » Brings digital signals out of tracking volume
    - » Provides chip control signals
    - » Power for chip and bias voltage

SVX4 Chip

- Nov '00 decision to employ common readout chip for CDF and DØ
  - SVX4 in deep sub-micron, 0.25 µm technology, intrinsically rad-hard
    - » Brand new chip with own personality/features
  - Commercial foundries used (TSMC)
- Test chips
  - MOSIS submission of FE 06/04/01
    - » Decided on pre-amp and pipeline design
    - » ENC = 450e + 43.0e/pF (optimum)
  - MOSIS submission of full chip 03/28/02
    - » Submission delay of ~5 months
    - » Two versions of chip (same padring)
      - On chip bypassing employed (DØ)
      - On chip bypassing not used (CDF)
    - » Both projects get ~300 chips each
    - » Projects need working chips to certify all readout electronics components



- Project assumes in its schedule that second full chip submission is needed
  - Second submission: October '02
  - Production submission: April '03
  - SVX4 drives the schedule

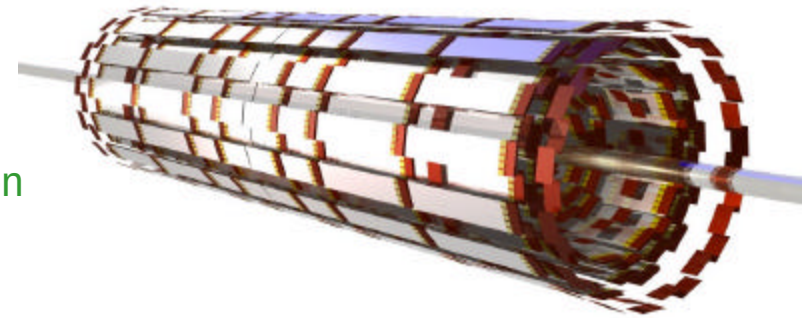
Parameters of Proposed Detector

	Layer 0A	Layer 0B	Layer 1A	Layer 1B	Layer 2A	Layer 2B	Layer 3A	Layer 3B	Layer 4A	Layer 4B	Layer 5A	Layer 5B	Total
Strip orientation	A	A	A	A	A+S	A+S	A+S	A+S	A+S	A+S	A+S	A+S	
# sectors	6	6	6	6	6	6	9	9	12	12	15	15	
# sensors in z	12	12	12	12	10	10	10	10	12	12	12	12	
Total # sensors	72	72	72	72	120	120	180	180	288	288	360	360	**2184**
Pitch (μm)	25	25	29	29	30	30	30	30	30	30	30	30	
Readout Pitch (μm)	50	50	58	58	60	60	60	60	60	60	60	60	
Sensor Active Width	12.8	12.8	22.3	22.3	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	
Sensor Cut Width	15.5	15.5	25.0	25.0	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	
Sensor Active Length	76.4	76.4	76.4	76.4	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	
Sensor Cut Length	79.4	79.4	79.4	79.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Radius Axial	17.8	24.7	34.8	39.1	53.2	68.9	89.3	103.4	116.9	130.6	150.1	163.6	
Radius Stereo	---	---	---	---	56.3	72.0	86.2	100.3	120.0	133.7	147.0	160.5	
Axial Coverage (%)	65.9	48.5	59.1	53.1	66.1	51.9	60.7	52.6	62.2	55.8	60.8	55.8	
Stereo Coverage (%)	---	---	---	---	62.7	49.8	62.8	54.2	60.6	54.5	62.0	56.8	
Silicon Area (m^2)	0.09	0.09	0.14	0.14	0.49	0.49	0.74	0.74	1.18	1.18	1.48	1.48	**8.26**
dphi/dz for stereo					Positive	Positive	Negative	Negative	Positive	Positive	Negative	Negative	
# RO segments in z	12	12	12	12	8	8	8	8	8	8	8	8	
# SVX4 chips per RO	2	2	3	3	5	5	5	5	5	5	5	5	
# Hybrids in z	12	12	6	6	4	4	4	4	4	4	4	4	
Total # Hybrids	72	72	36	36	48	48	72	72	96	96	120	120	**888**
# SVX4 chips	144	144	216	216	480	480	720	720	960	960	1200	1200	**7440**
# RO channels	18,432	18,432	27,648	27,648	61,440	61,440	92,160	92,160	122,880	122,880	153,600	153,600	**952,320**

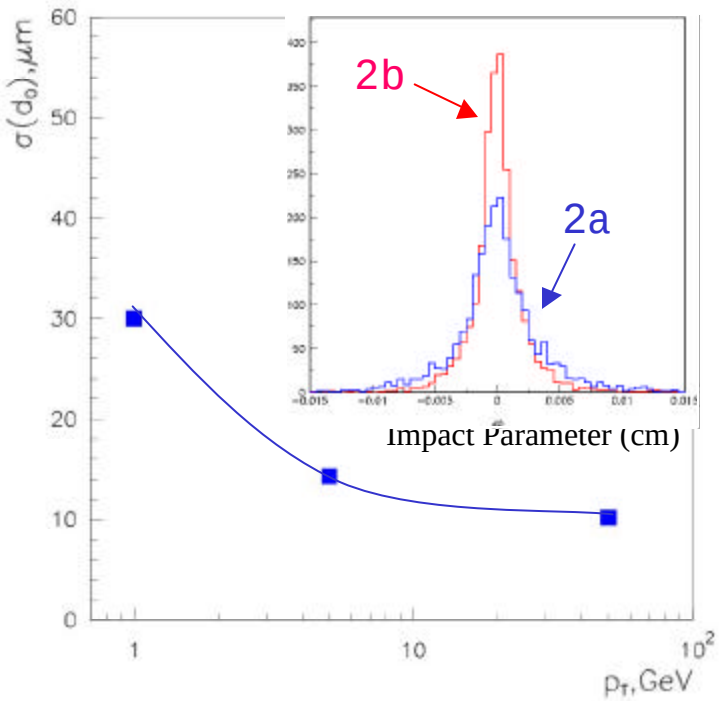
- Few Characteristics:
  - Sensors: 2184; Silicon area of 8.3 m^2
  - 888 hybrids, i.e readout cables (Run2a: 912)
  - 7440 SVX4 chips for a total of 952320 channels (Run2a: 792576)

Performance of Proposed Detector

- Performance studies based on full Geant simulation
  - Full model of geometry and material
  - Model of noise, mean of 2.1 ADC counts
  - Single hit resolution of ~10 μm
  - Longitudinal segmentation implemented
  - Pattern recognition and track reconstruction

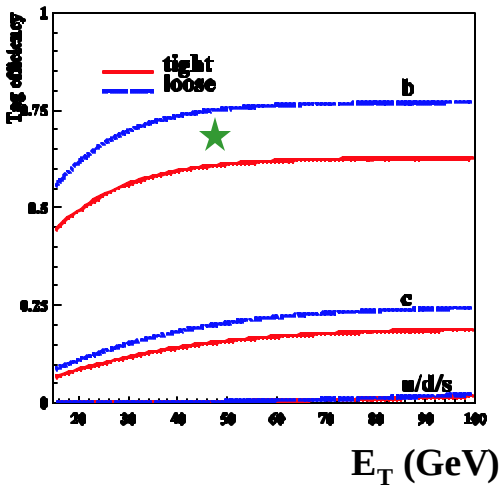


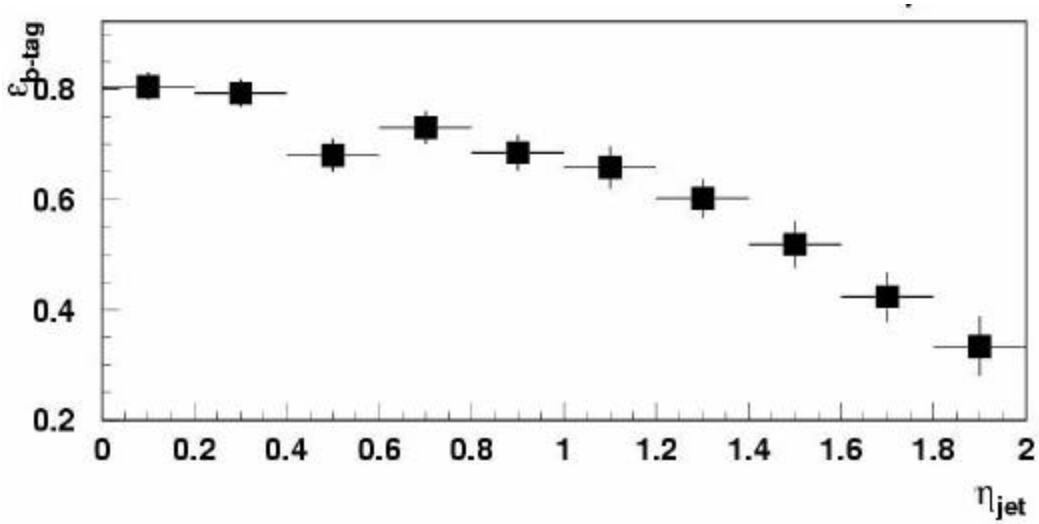
- Benchmarks
  - $\sigma(1/p_T)$ =
    - » $\sigma(p_T)/P_T$ ~ 3% at 10 GeV/c
  - $\sigma(d_0)^2 = C^2 + (A/p_T)^2$
    - » $\sigma(d_0)$ < 15 μm for p_T > 10 GeV/c



Performance of Proposed Detector

- B-tagging
  - Loose b-tag algorithm: signed impact parameter, $E_b > 20$ GeV
    - » Track selection
      - within cone $\Delta R < 0.5$ of b-jet
      - $p_T > 0.5$ GeV/c, good χ^2, hits in silicon ≥ 2
    - » Impact parameter significance
      - 2 tracks: $d_0/\sigma(d_0) > 3$
      - 3 tracks: $d_0/\sigma(d_0) > 2$
  - b-jet tagging efficiency of ~ 65% per jet
    - » Compare to Higgs working group assumptions

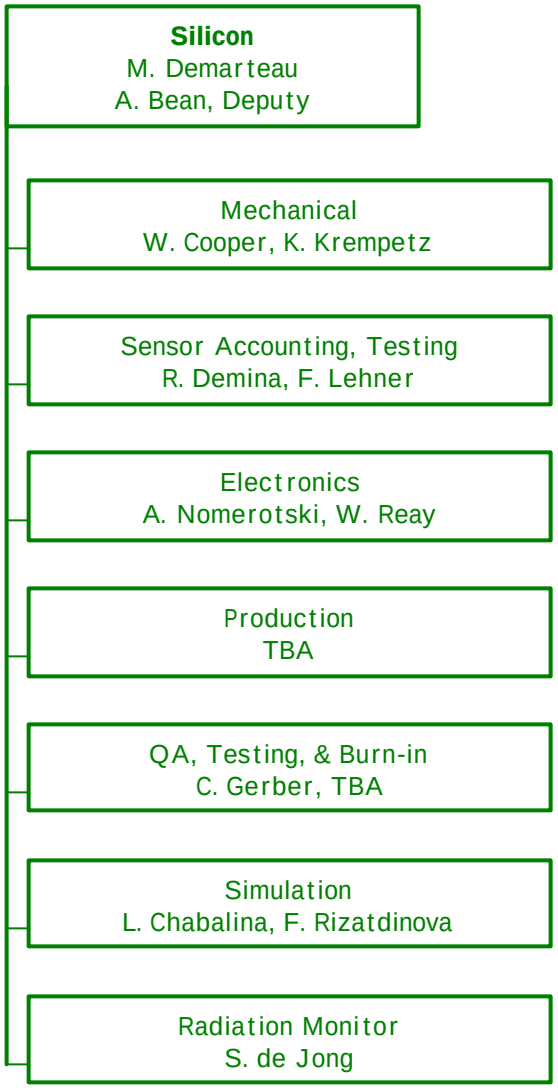




	TDR
$P(n_b \geq 1)$	76%
$P(n_b \geq 2)$	29%
Mistag Rate	< 1.5 %

Based on WH-events, with b's falling within acceptance

Organization



- Major commitments from various groups
  - Mechanical
    - » University of Washington: Layer 0, 1
  - Sensor Testing
    - » Kansas State University
    - » Stony Brook
    - » Cinvestav
  - Electronics
    - » Kansas State University
      - Digital cables, Adapter card
    - » University of Kansas
      - Hybrid testing
    - » Louisiana Tech
      - Digital cable testing
  - QA
    - » UIC
    - » Northwestern
  - Radiation Monitoring
    - » NIKHEF, Amsterdam
  - Temperature Monitoring
    - » Rice University
- Trying to strengthen group further

Cost and NSF Funding

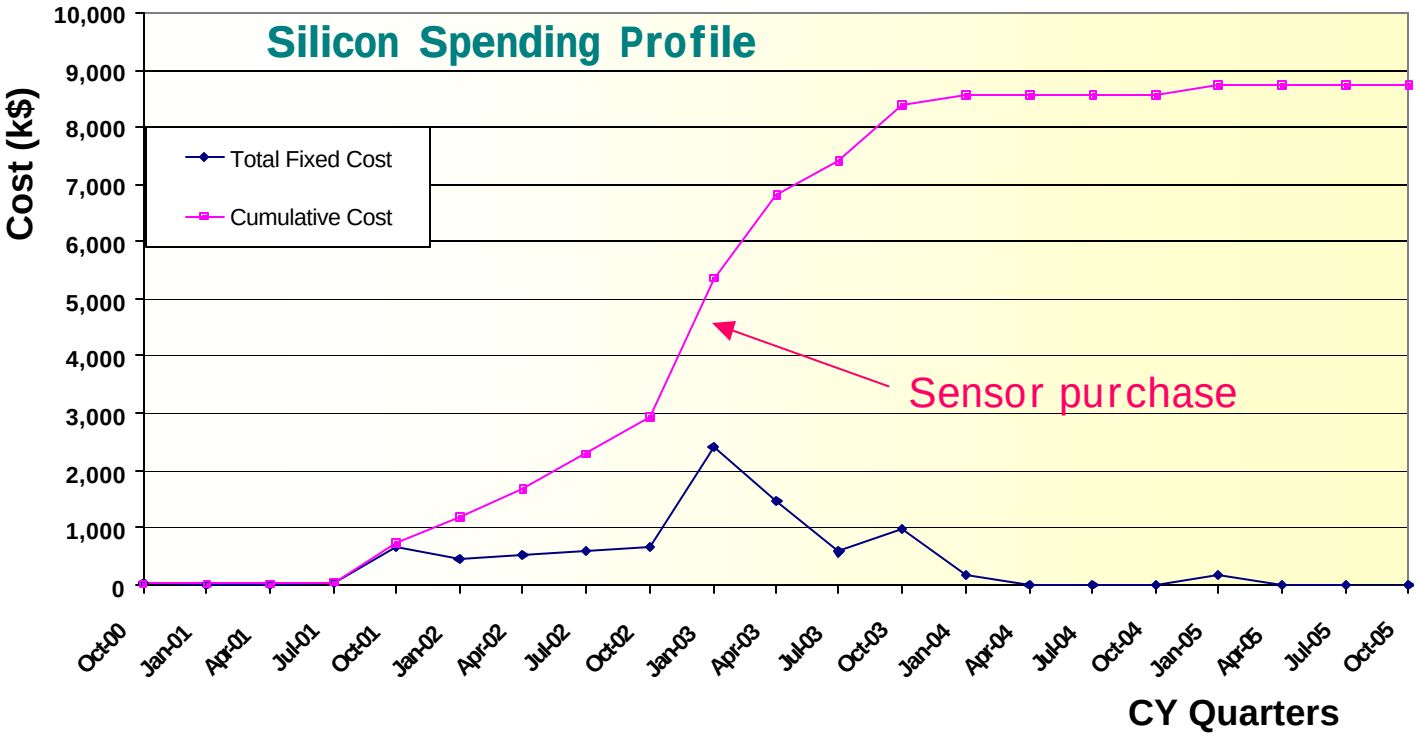
M&S 1.1	ITEM SILICON TRACKER	M&S TOTAL	CONTINGENCY %	CONTINGENCY Cost	TOTAL Cost
1.1.1	*Silicon Sensors*	2,678,531	25	681,640	3,360,171
1.1.2	*Readout System*	4,029,215	45	1,797,590	5,826,805
1.1.3	*Mechanical Design and Fabrication*	1,340,696	51	679,818	2,020,514
1.1.4	*Detector Assembly and Testing*	445,250	37	165,415	610,665
1.1.5	*Monitoring*	55,000	45	24,500	79,500
1.1.6	*Installation*	90,000	47	42,500	132,500
1.1.7	*Computing*	101,000	11	11,400	112,400
1.1	**SILICON TRACKER**	**8,739,692**	**39**	**3,402,863**	**12,142,555**

- Cost drivers
  - Silicon sensors
  - Cables: analogue, digital and twisted pair in near equal amounts
  - Hybrids
- Project has secured Major Research Instrumentation (MRI) Grant from NSF
  - $1.6M of NSF equipment funds and $800k of Cost Share by participating universities
    - » 10 participating universities; University of Kansas grant administrator

Approach to Cost Estimate

- Strongly relies on Run2a experience
  - Estimates for assembly, fixturing
  - Initial quotes for equipment
- General philosophy regarding contingency
  - Uniform 50%
  - Areas with little experience: 60%
  - Quote in hand, or previously purchased commercial items: 30%
  - Spare count part of production cost, never included in contingency
  - Items already purchased: 0%
- MRI contribution
  - MRI contribution is fixed dollar amount
  - When identified as such in M&S cost estimate, assumed no contingency
  - Permits to verify overall level of contingency

Cost Profile



- Total obligations to date: ~835 k$
  - Majority spent on MRI funds

Schedule

- Need to add

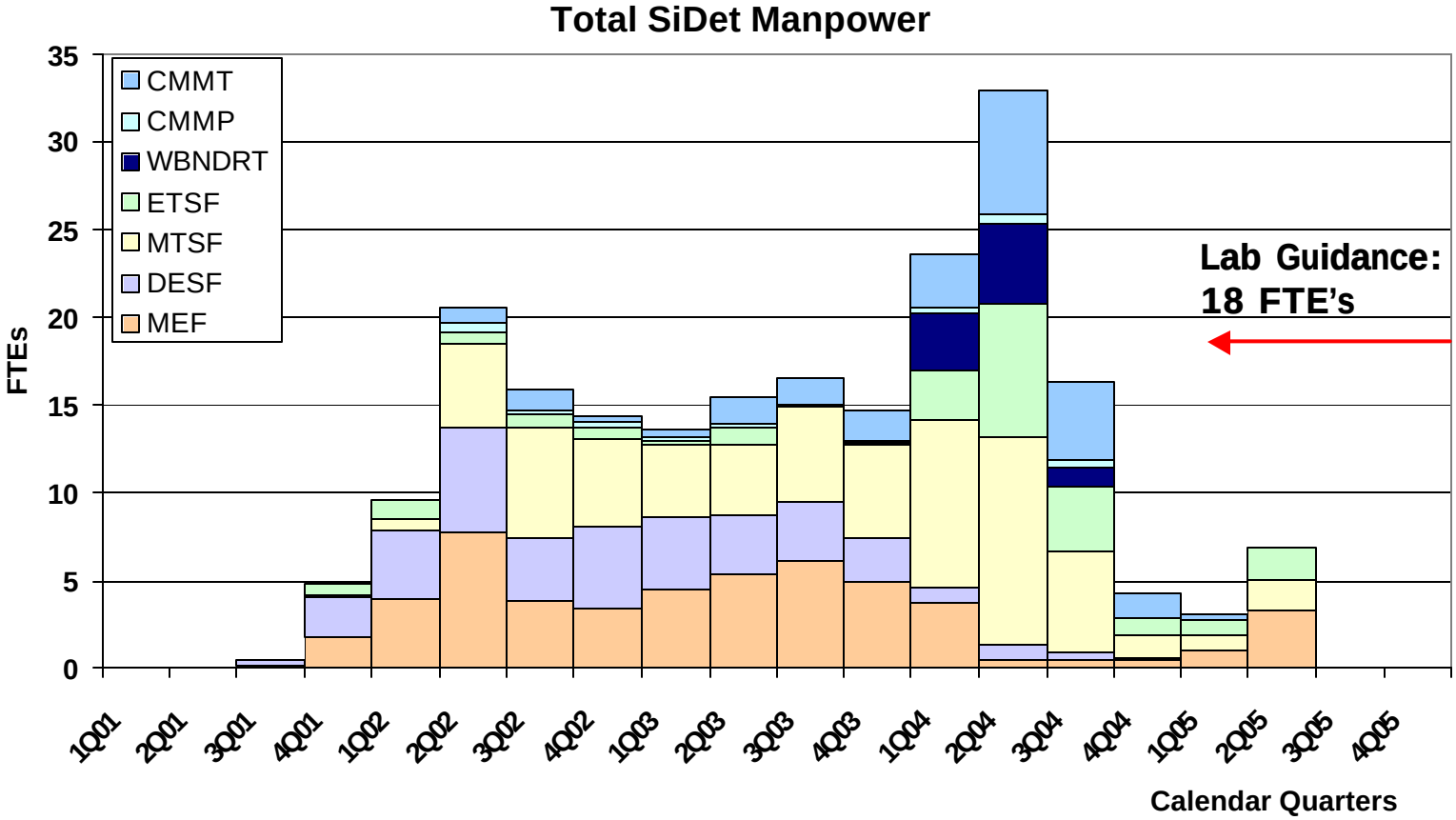
Approach to Labor Estimate

- Blanket assumption for labor:
  - 1456 hrs/yr or 364 hrs/quarter, which corresponds to 70% efficiency
    - » 52 weeks/yr * 5 days/week - 39 days vacation, sick, holidays = 221 days, which corresponds to 85% efficiency
    - » Efficiency of use of those available hours 82% (meetings, coffee break, bathroom break, …)
  - When converting hours of labor into FTE's, this number is applied

- In addition, there's an efficiency factor folded in task by task
  - Example: 10-10 axial Module production
    - » Duration: 8 weeks, 2.1 modules/day
    - » Resources: 0.5 CMMT, 0.5 MTF
      - In production mode, module assembly should take about 1 hour/module
      - Needs some setup time, cleanup time, and things may go wrong

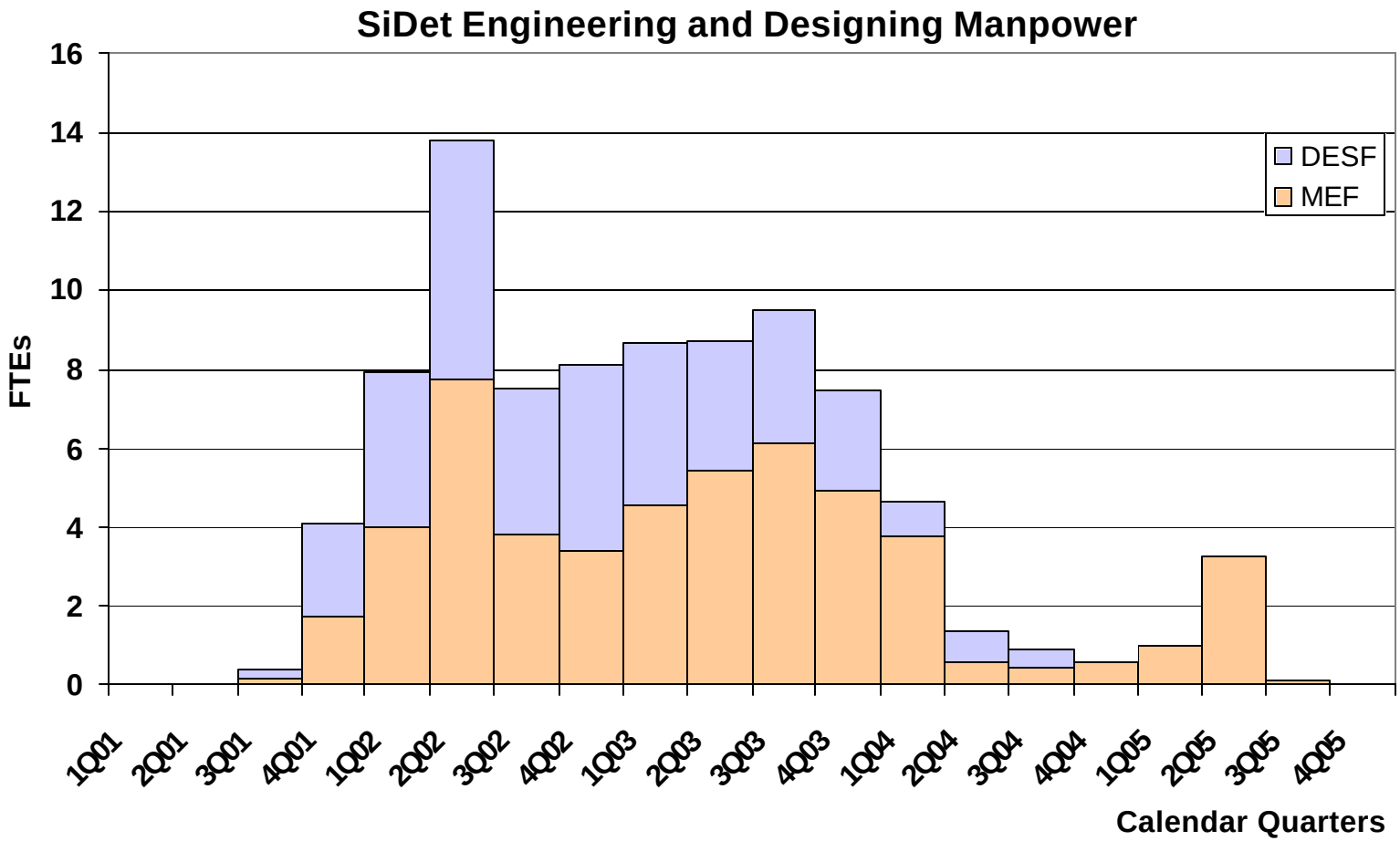
Total SiDet Manpower Needs

- Comparison of total manpower needs for SiDet where laboratory has given guidance



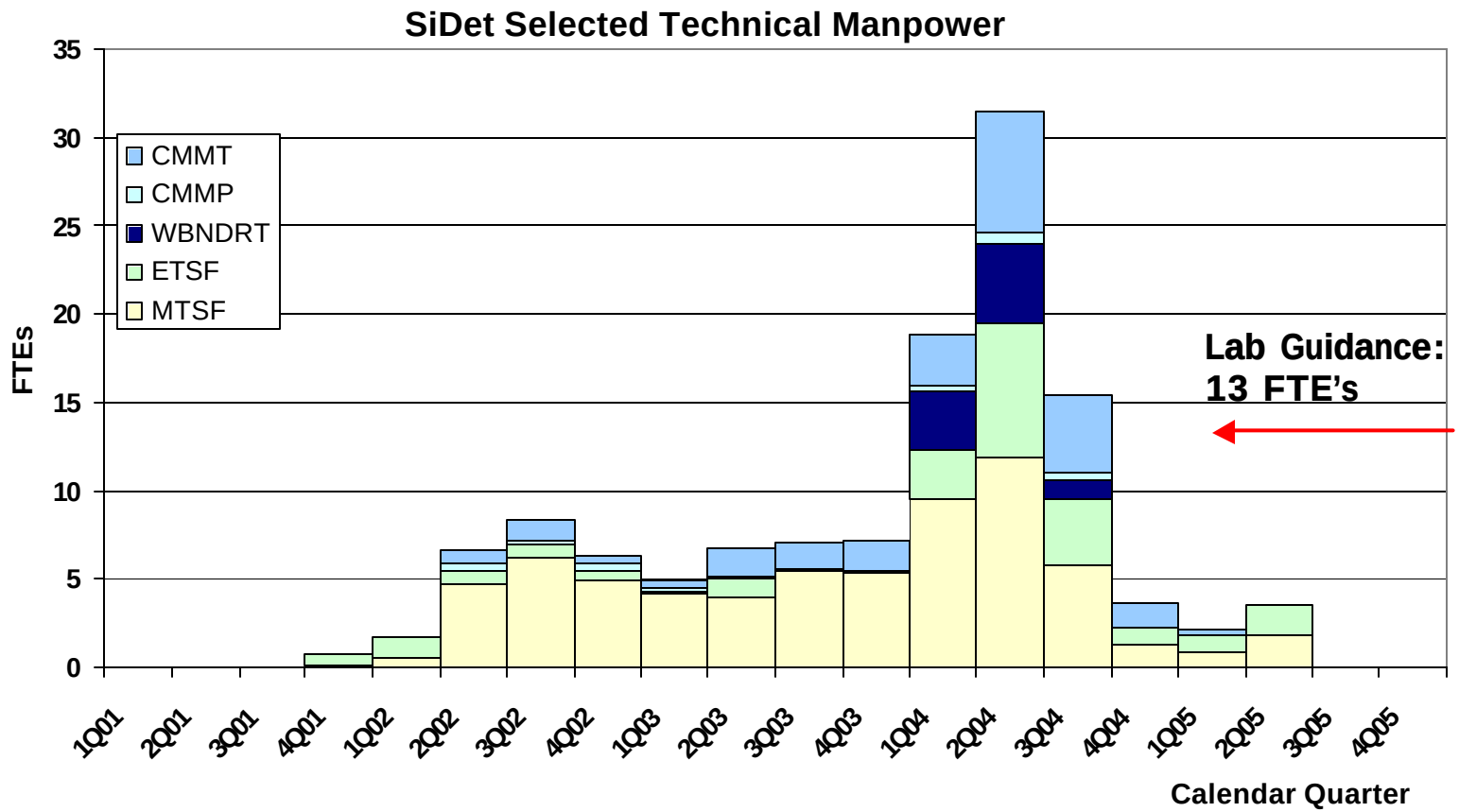
Selected SiDet Manpower Needs

- Projected needs for mechanical engineers and designers



Selected SiDet Manpower Needs

- Comparison of technical manpower needs for SiDet where laboratory has given guidance

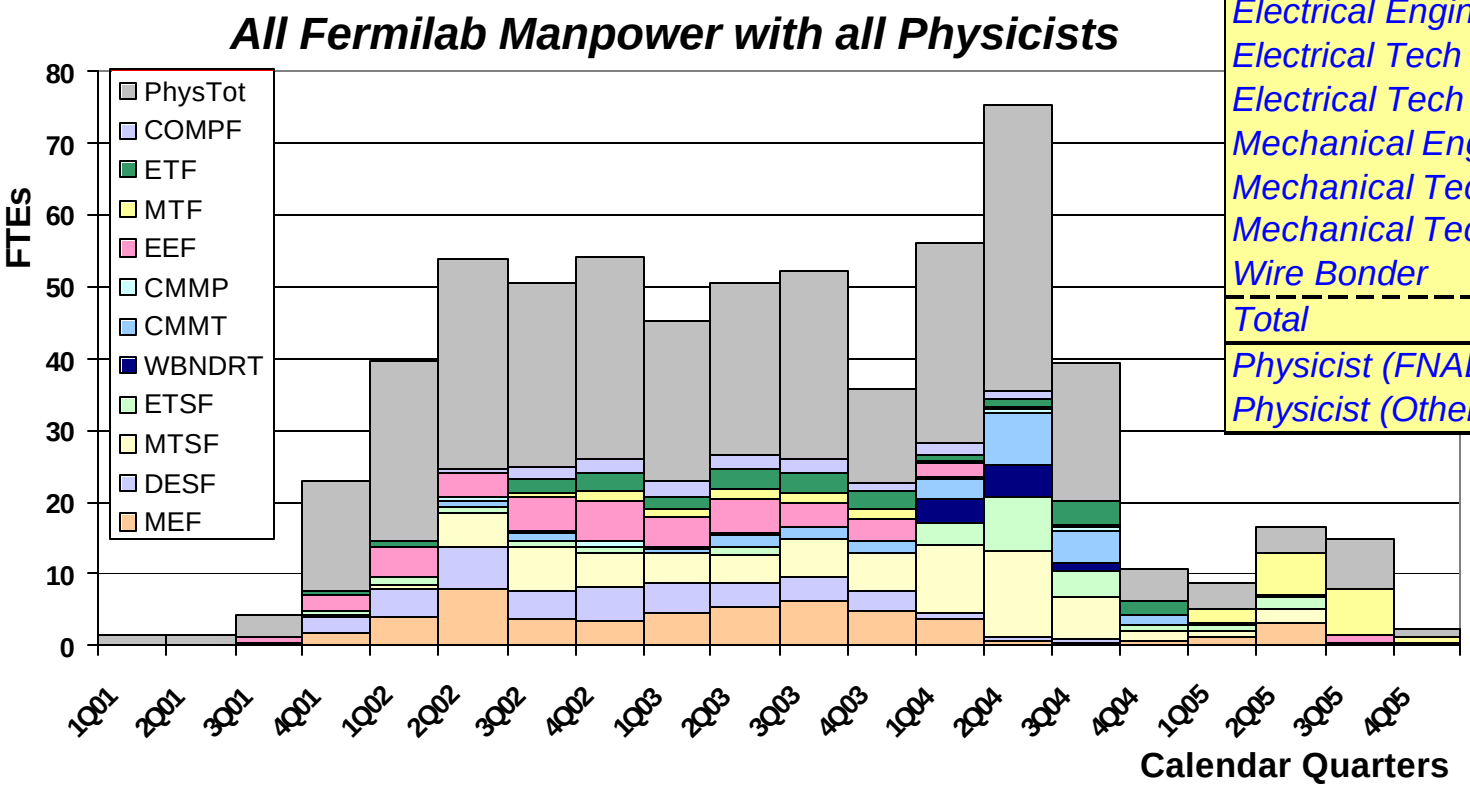


- Note, work performed by CMM technicians was performed by graduate students and post-docs during the assembly phase of Run2a

Total Fermilab Manpower Estimate

- Add all Fermilab manpower and all physicists from Fermilab and Universities

FNAL Resources	Person-yrs
CMM Prog	0.8
CMM Tech	5.9
Computing Prof.	3.4
Designer/Drafter	9.1
Electrical Engineer	10.2
Electrical Tech	5.9
Electrical Tech - SiDet	5.9
Mechanical Engineer	13.3
Mechanical Tech	6.3
Mechanical Tech - Sidet	16.6
Wire Bonder	2.2
Total	79.7
Physicist (FNAL)	34.9
Physicist (Other)	46.1



Concluding Remarks

- The Run2b upgrades will allow us to exploit the unique opportunity for discovery available to the Laboratory which, however, is only available within limited time frame
- The silicon detector proposed is well suited to address the physics issues of Run2b
  - Emphasis on impact parameter measurement at small radii
  - The design is conservative, not overextended
- A lot of progress has been made over the course of last year and the project is well into the prototyping phase
- Some significant issues remain
  - Potential schedule risks (SVX4)
  - Future manpower needs
  - Adequate funding

- The collaboration is committed to building this new detector
  - It is the detector we would like to build
  - It is the detector we would like to get baselined
- We are looking for your advice to help us achieve that goal

Nomenclature

- MEF — Mechanical Engineer, Fermilab
- DESF — Designer, Fermilab
- MTSF — Mechanical Technician, SiDet, Fermilab
- ETSF — Electrical Technician, SiDet, Fermilab
- WBNDRT — Wirebonder Technician
- CMMT — Coordinate Measuring Machine Technician
- CMMP — Coordinate Measuring Machine Programmer
- EEF — Electrical Engineer Fermilab
- MTF — Mechanical Technician, Fermilab (non-SiDet)
- ETF — Electrical Technician, Fermilab (non-SiDet)
- COMPF — Computing Professional, Fermilab

- F — as last letter indicates Fermilab resource
- U — as last letter indicates University resource paid for by MRI funds
- O — as last letter indicates University resource