OT B04: 402.02 Outer Tracker Risks

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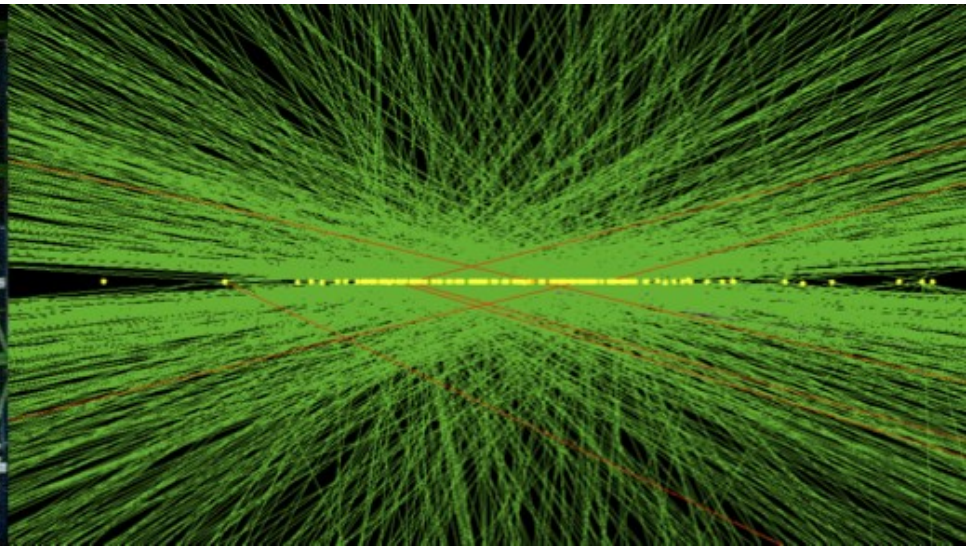
CD1 Director's Review

March 20, 2019



Outline

- Introduction
- Risk Summary
- Talk Summary

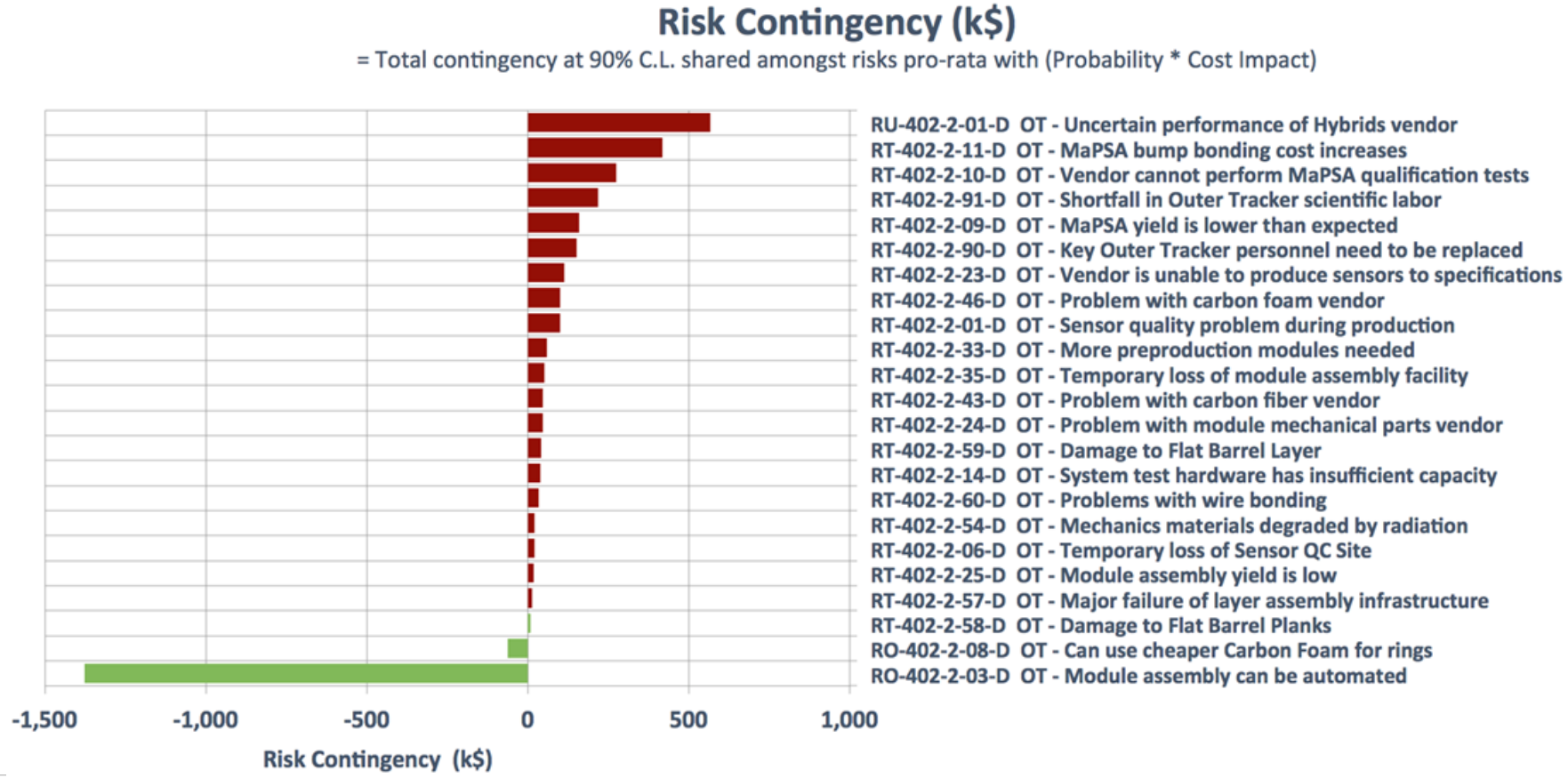
402.2 OT Risks

FNAL Risk Procedures: PPP-doc-65
Risk Register: DocDb 13480

- At June 2018 IPR
  - Project Office owns Exchange Rate, Contributed Labor, Fermilab Overhead, and Critical Attrition risks – all impact OT
  - OT Specific: 16 Threats, 2 Opportunities, and 1 Uncertainty
- Since then
  - Risk Workshop 9/7/2018 Agenda
    - External Reviewers: Aseet Mukherjee, Jeff Spalding
    - Outcome: One Risk split into two with high/low impact, added critical personnel at Rutgers, wirebonding risk, modified burn rates to be L3 specific
  - Critical Attrition and Contributed Labor risks moved into L2 areas
- Outer Tracker Threats: 1.8M $\rightarrow$ 2.5M @90% C.L.
  - {Probability $\times$ Impact}: \$720k $\rightarrow$ \$1.2M

Quick Risk Summary

- 20 Threats and 1 Uncertainty: P × $ = $1,198k
  - Was $720k in June 2018, (Contributed Labor + Key personnel = 178k)
- 2 Opportunities: P × $ = $690k (666k in June 2018)
  - Dominated by Automation opportunity
- Risk Assessment constantly evolving



OT Current Risks

WBS / Ops Lab Activity : 402.2 OT - Outer Tracker (23)

Risk Type : Uncertainty (1)

3 (High)	RU-402-2-01-D	OT - Uncertain performance of Hybrids vendor	100 %	0 -- 168 -- 648 k$	0 -- 2 -- 12 months	272

Risk Type : Threat (20)

3 (High)	RT-402-2-91-D	OT - Shortfall in Outer Tracker scientific labor	30 %	0 -- 0 -- 1049 k$	0 months	105
3 (High)	RT-402-2-01-D	OT - Sensor quality problem during production	50 %	46 -- 79 -- 163 k$	2 -- 3 -- 6 months	48
3 (High)	RT-402-2-46-D	OT - Problem with carbon foam vendor	25 %	23 -- 158 -- 396 k$	1 -- 6 -- 12 months	48
2 (Medium)	RT-402-2-11-D	OT - MaPSA bump bonding cost increases	20 %	500 -- 1000 -- 1500 k$	0 months	200
2 (Medium)	RT-402-2-10-D	OT - Vendor cannot perform MaPSA qualification tests	33 %	200 -- 400 -- 600 k$	0 months	132
2 (Medium)	RT-402-2-09-D	OT - MaPSA yield is lower than expected	15 %	370 -- 640 k$	0 months	76
2 (Medium)	RT-402-2-90-D	OT - Key Outer Tracker personnel need to be replaced	25 %	75 -- 225 -- 570 k$	0 -- 0 -- 3 months	73
2 (Medium)	RT-402-2-23-D	OT - Vendor is unable to produce sensors to specifications	5 %	210 -- 315 -- 2720 k$	6 -- 9 -- 12 months	54
2 (Medium)	RT-402-2-33-D	OT - More preproduction modules needed	25 %	0 -- 0 -- 330 k$	0 -- 0 -- 6 months	28
2 (Medium)	RT-402-2-35-D	OT - Temporary loss of module assembly facility	50 %	50 k$	1 months	25
2 (Medium)	RT-402-2-24-D	OT - Problem with module mechanical parts vendor	20 %	0 -- 0 -- 324 k$	0 -- 0 -- 6 months	22
2 (Medium)	RT-402-2-43-D	OT - Problem with carbon fiber vendor	25 %	23 -- 79 -- 158 k$	1 -- 3 -- 6 months	22
2 (Medium)	RT-402-2-59-D	OT - Damage to Flat Barrel Layer	1 %	930 -- 1880 -- 3150 k$	6 -- 9 -- 12 months	20
2 (Medium)	RT-402-2-14-D	OT - System test hardware has insufficient capacity	10 %	71 -- 169 -- 292 k$	2 -- 3 -- 4 months	18
2 (Medium)	RT-402-2-60-D	OT - Problems with wire bonding	80 %	13.5 -- 27 k$	1 -- 2 months	16
2 (Medium)	RT-402-2-06-D	OT - Temporary loss of Sensor QC Site	20 %	22 -- 48 -- 86 k$	1 -- 2 -- 4 months	10
2 (Medium)	RT-402-2-54-D	OT - Mechanics materials degraded by radiation	10 %	48 -- 96 -- 144 k$	1 -- 2 -- 3 months	10
2 (Medium)	RT-402-2-25-D	OT - Module assembly yield is low	10 %	0 -- 40 -- 240 k$	0 -- 0 -- 6 months	9
2 (Medium)	RT-402-2-58-D	OT - Damage to Flat Barrel Planks	5 %	30 -- 91 -- 141 k$	1 -- 1 -- 2 months	4
1 (Low)	RT-402-2-57-D	OT - Major failure of layer assembly infrastructure	5 %	56 -- 112 -- 178 k$	2 -- 4 -- 6 months	6

Risk Type : Opportunity (2)

3 (High)	RO-402-2-03-D	OT - Module assembly can be automated	66 %	-1000 k$	-2 months	-660
2 (Medium)	RO-402-2-08-D	OT - Can use cheaper Carbon Foam for rings	50 %	-60 k$	0 months	-30

Risk Summary

- OT Threats sum to $2.5M @ 90% C.L. (~ 5% BAC)
  - Covering a broad range of potential events that may transpire during the project
- Risk analysis will continue to evolve as we move towards baseline
- List of each Risk follows…

OT Risks

RO-402-2-03-D OT - Module assembly can be automated

Risk Rank:	3 (High) **Scores:** Probability : 5 (VH) ; Cost: 2 (M) Schedule: 1 (L))		**Risk Status:**	Open	
Summary:	If automation in module assembly comes to fruition, then labor costs and schedule durations both decrease				
Risk Type:	Opportunity		**Owner:**	Leonard G Spiegel	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	External Risk / Facilities	
Probability (P):	66%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 1-point - single value	**Schedule Impact:**	PDF	= 1-point - single value
	Minimum	= k$		Minimum	= months
	Most likely	= -1000 k$		Most likely	= -2 months
	Maximum	= k$		Maximum	= months
	Mean	= -1000 k$		Mean	= -2 months
	P * <Impact>	= -660 k$		P * <Impact>	= -1.3 months
Basis of Estimate:	A reduction of $1.6M in fully burdened labor costs throughout the production period is determined assuming that 2 technicians per assembly site are replaced with 2 students (uncosted graduate students at FNAL and moderately costed undergraduates at Brown = $30/hr). The cost of two gantry robots ($150k each) and engineering+programming development costs ($300k) leads to a $1.0M opportunity. The impact on the schedule is expected to be 2 months of savings based on the current estimate of the labor required to carry our the steps being considered for automation.				
Cause or Trigger:			**Impacted Activities:**	All PS and 2S Module assembly activities in aggregate. Implemented as a risk hook between start and completion of production o 2S modules.	
Start date:	1/Oct/2019		**End date:**	1/Oct/2022	
Risk Mitigations:	In the R&D phase we will pro-actively explore automating certain steps in the module assembly process with the aim of realising the associated cost and schedule savings.				
Risk Responses:	Accept the risk , produce modules more efficiently				
More details:					

RO-402-2-08-D OT - Can use cheaper Carbon Foam for rings

Risk Rank:	2 (Medium) **Scores:** Probability : 4 (H) ; Cost: 1 (L) Schedule: 0 (N))		**Risk Status:**	Open	
Summary:	If cheaper Carbon Foam shows acceptable performance for the rings, the potential decrease in the cost of the carbon foam may benefit the project budget				
Risk Type:	Opportunity		**Owner:**	Stefan Gruenendahl	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	External Risk / Market	
Probability (P):	50%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 1-point - single value	**Schedule Impact:**	PDF	= 1-point - single value
	Minimum	= k$		Minimum	= months
	Most likely	= -60 k$		Most likely	= 0 months
	Maximum	= k$		Maximum	= months
	Mean	= -60 k$		Mean	= 0 months
	P * <Impact>	= -30 k$		P * <Impact>	= 0.0 months
Basis of Estimate:	Estimate that the cost could be halved (reduced from $120k to $60k).				
Cause or Trigger:	Ring prototypes built with mechanical grade (cheaper) carbon foam meet QC criteria (precision, stiffness)		**Impacted Activities:**	Carbon foam procurements	
Start date:	1/Jan/2020		**End date:**	31/Dec/2024	
Risk Mitigations:	We are evaluating ring prototypes built with mechanical grade (cheaper) carbon foam. Results obtained so far (first pair of prototypes) look promising.				
Risk Responses:	Accept opportunity				
More details:					

RT-402-2-01-D OT - Sensor quality problem during production

Risk Rank:	3 (High) **Scores:** Probability : 4 (H) ; Cost: 1 (L) Schedule: 2 (M))		**Risk Status:**	Open	
Summary:	If the sensor vendor delivers sensors that do not meet specifications then the degraded performance of the tracker jeopardizes the physics performance of the upgraded detector.				
Risk Type:	Threat		**Owner:**	Ulrich Heintz	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	External Risk / Vendors	
Probability (P):	50%		**Technical Impact:**	2 (M) - significantly substandard	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 46 k$		Minimum	= 2 months
	Most likely	= 79 k$		Most likely	= 3 months
	Maximum	= 163 k$		Maximum	= 6 months
	Mean	= 96 k$		Mean	= 3.67 months
	P * <Impact>	= 48 k$		P * <Impact>	= 1.8 months
Basis of Estimate:	The contract will be written for the vendor to deliver a specified number of good sensors that satisfy CMS specifications. Thus we do not have to pay for sensors that do not satisfy the specifications and there is no impact on sensor cost. The only cost impact is that we will have to repeat the QC testing of the replacement sensors. Minimal impact: this happens during production and is corrected quickly after feedback from sensor QC leading to a delay of about 2 months and negligible direct cost. Maximal schedule impact: this happens during preproduction and the preproduction cycle has to be repeated, leading to a delay of about 6 months and extra labor cost of about $25k (cost for preproduction cycle of one sensor type). The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). **Min cost = $0k + 2months * $23k burn rate = $46k.** **Likely cost = $10k + 3month * $23k burn rate = $79k.** **Max cost = $25k + 6months * $23k burn rate = $163k.** The problem has to either persist over many batches or not be noticed during QC at the vendor (for example a degradation of performance over some time). Problems that affect a single batch of sensors (eg because of some contamination or processing mistake) will not lead to a significant delay because reprocessing a batch will only add a week or two to the production period. Based on past experience with the vendor we expect this t happen at least once during production and we assign 50% probability for each sensor type.				
Cause or Trigger:	Sensors do not satisfy specifications		**Impacted Activities:**	Sensor procurement activities and downstream activities. This applies to each type of sensor, but the probability should be 5% per type (PS-s, PS-p, 2S)	
Start date:	1/Apr/2020		**End date:**	31/Dec/2024	
Risk Mitigations:	We carry out extensive prototyping work with the vendors prior to placing the contract for sensor production to make sure that vensors understan our specifications and can meet them. The vendor will carry out a first set of QC measurements before the sensors are shipped to CERN and distributed to QC centers. This ensures that most problems will be caught quickly and do not lead to significant impact on the project. The cost of these measurements is factured into the sensor cost.				
Risk Responses:	If a modest problem occurs, work closely with vendor to solve it (e.g. testing). Replace the flawed sensors.				

RT-402-2-06-D OT - Temporary loss of Sensor QC Site

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 1 (L) Schedule: 2 (M))	**Risk Status:**	Open
Summary:	If a Sensor QC facility temporarily becomes inoperable due to loss or damage of critical equipment (e.g. due to a water leak) then the resultant dip in sensor throughput may jeopardize timely completion of the project.		
Risk Type:	Threat	**Owner:**	Ulrich Heintz
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	Technical Risk / ES&H
Probability (P):	20%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = 22 k$ Most likely = 48 k$ Maximum = 86 k$ Mean = 52 k$ P * <Impact> = 10 k$	**Schedule Impact:**	PDF = 3-point - triangular Minimum = 1 months Most likely = 2 months Maximum = 4 months Mean = 2.33 months P * <Impact> = 0.5 months
Basis of Estimate:	Probability = 20% is approximately estimated from 2 sites * 10% per site. This is based on experience from original CMS tracker, original pixel, and Phase 1 pixel where one incident occurred in O(10) sites. If one center has a major equipment failure the second center can pick up the additional load within the 100% cushion. Min/likely/max delay = 1/2/4 months delay for the inefficiency in the logistics to transfer materials and people back and forth. Min/likely/max repair estimate is 10/25/40 k$. This assumes insurance will cover loss/damage of major equipment. The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). **Min cost = $10k + 1 month * $23k burn rate = $33k.** **Likely cost = $25k + 2 months * $23k burn rate = $71k.** **Max cost = $40k + 4months * $23k burn rate = $132k.**		
Cause or Trigger:		**Impacted Activities:**	This is implemented as two independent risk events for the two QC sites (Brown and Rochester). At each site, 3 tasks are impacted in a correlated way, representing the QC work on the 3 sensor types. The impact is modeled in the middle of the QC work (Lot 5).
Start date:	1/Apr/2020	**End date:**	31/Dec/2024
Risk Mitigations:	Having two sites is already a hedge against the complete stoppage of sensor testing, and should one site become temporarily inoperable, sensors w ould be redirected to the other site temporarily to mitigate the impact.		
Risk Responses:	Sensors can be diverted to the unaffected site to utilize its full throughput, and additional resources added to increase module production throughput at both sites (once the affected one is re-established) to regain time in the schedule.		
More details:	CMS-doc-13481		

RT-402-2-09-D OT - MaPSA yield is lower than expected

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 2 (M) Schedule: 0 (N))		**Risk Status:**	Open	
Summary:	If MaPSA yield is lower than expected, the additional wastage also sacrifices the associated sensors and MPA chips, which would need to be replaced at the project's cost.				
Risk Type:	Threat		**Owner:**	Ron Lipton	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	Technical Risk / Quality	
Probability (P):	15%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 2-point - flat range	**Schedule Impact:**	PDF	= 1-point - single value
	Minimum	= 370 k$		Minimum	= months
	Most likely	= k$		Most likely	= 0 months
	Maximum	= 640 k$		Maximum	= months
	Mean	= 505 k$		Mean	= 0 months
	P * <Impact>	= 76 k$		P * <Impact>	= 0.0 months
Basis of Estimate:	For each loss of 10% in yield, we would need 10% more sensors, estimated at 245k, and 10% more MPA chips, estimated at 125k. The range covers wastage between 10 and 20%. Implemented between Testing batch 3 and Vendor producing batch 5.				
Cause or Trigger:	A myriad number of problems at the bump bonding stage might reduce the yield, or handling during the assembly.		**Impacted Activities:**	Increased wastage during the MaPSA assembly would require additional components, namely PS sensors and MPA chips	
Start date:	2/Sep/2021		**End date:**	20/Sep/2023	
Risk Mitigations:					
Risk Responses:					
More details:					

RT-402-2-10-D OT - Vendor cannot perform MaPSA qualification tests

Risk Rank:	2 (Medium) **Scores:** Probability : 3 (M) ; Cost: 2 (M) Schedule: 0 (N))		**Risk Status:**	Open	
Summary:	MaPSA qualification is done at the vendor site. The current cost estimate may increase considerably if the vendors do not have the proper infrastructure to qualify the parts.				
Risk Type:	Threat		**Owner:**	Ron Lipton	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	Technical Risk / Complexity	
Probability (P):	33%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 1-point - single value
	Minimum	= 200 k$		Minimum	= months
	Most likely	= 400 k$		Most likely	= 0 months
	Maximum	= 600 k$		Maximum	= months
	Mean	= 400 k$		Mean	= 0 months
	P * <Impact>	= 132 k$		P * <Impact>	= 0.0 months
Basis of Estimate:	Qualification of MaPSAs may require sophisticated probing equipment, which can cost up between 200-600k for procurement, installation, and comissioning of the requisite equipment, potentially at several vendors.				
Cause or Trigger:			**Impacted Activities:**	MaPSA procurement costs would increase. Implemented as a cost increase after round 2 of MaPSA prototyping.	
Start date:	1/Jan/2019		**End date:**	14/Jun/2023	
Risk Mitigations:					
Risk Responses:	Work with vendor to improve their infrastructure or move testing to different site (other vendor or collaborator)				
More details:					

RT-402-2-11-D OT - MaPSA bump bonding cost increases

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 3 (H) Schedule: 0 (N))		**Risk Status:**	Open	
Summary:	Currently we have several MaPSA estimates,with a very broad range between high and low, indicating the industry does not give a clear indication of the actual cost. This risk is to cover the possibility that this high cost item exceeds the nominal estimate uncertainty, M5 at the moment.				
Risk Type:	Threat		**Owner:**	Ron Lipton	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	External Risk / Vendors	
Probability (P):	20%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 1-point - single value
	Minimum	= 500 k$		Minimum	= months
	Most likely	= 1000 k$		Most likely	= 0 months
	Maximum	= 1500 k$		Maximum	= months
	Mean	= 1000 k$		Mean	= 0 months
	P * <Impact>	= 200 k$		P * <Impact>	= 0.0 months
Basis of Estimate:	Currently we have several MaPSA estimates,with a very broad range between high and low, indicating the industry does not give a clear indication c the actual cost. This risk is to cover the possibility that this high cost item exceeds the nominal estimate uncertainty, M5 at the moment.				
Cause or Trigger:			**Impacted Activities:**	The costs of MaPSA bump bonding would increase, increasing the costs of PS module fabrication.	
Start date:	1/Jan/2019		**End date:**	14/Jun/2023	
Risk Mitigations:	Prototypes will be used to validate low bidders, for which there is not yet confidence of delivering with requisite quality. There is more confidence for high cost bidders, which will also be validated in the prototyping phase, but even there the quotes are still preliminary.				
Risk Responses:					
More details:					

RT-402-2-14-D OT - System test hardware has insufficient capacity

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 2 (M) Schedule: 2 (M))	**Risk Status:**	Open
Summary:	If unforeseen problems occur during assembly and testing, then the baseline testing systems may not be sufficient to maintain the required throughput. This would necessitate the procurement and commissioning of additional test systems and additional labour for testing.		
Risk Type:	Threat	**Owner:**	Anadi Canepa
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	Technical Risk / Reliability or Performance
Probability (P):	10%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = 71 k$ Most likely = 169 k$ Maximum = 292 k$ Mean = 177 k$ P * <Impact> = 18 k$	**Schedule Impact:**	PDF = 3-point - triangular Minimum = 2 months Most likely = 3 months Maximum = 4 months Mean = 3 months P * <Impact> = 0.3 months
Basis of Estimate:	The maximum cost impact corresponds to a scenario in which the capacity of all the production test systems (total cost about $200k) needs to be doubled, i.e. a cost impact of $200k. The minimum and likely costs reflect the need to duplicate parts of the test systems. The min/likely/max schedule impact of 2/3/4 months is estimated assuming that the problem becomes apparent during production. The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). **Min impact = $25k + 2 months * $23k/month = $71k.** **Likely impact = $100k + 3 months * $23k/month = $169k.** **Max impact = $200k + 4 months * $23k = $292k.**		
Cause or Trigger:		**Impacted Activities:**	More module testing equipment would be required, possibly more cold boxes, single module testing, or hybrid testing equipment. Implemented as a cost impact on FNAL PS module production, A, East Coast PS Module production (B), FNAL 2S Module Production (C), and East Coast 2S module production (D). Sites should be delayed the same amount, but the probability should be split evenly between PS (A,C) and 2S (B,D)
Start date:	1/Jan/2022	**End date:**	31/Dec/2024
Risk Mitigations:	The testing hardware is an external deliverable. We will monitor the progress of the USCMS module production and ensure that new testing equipment is purchased when necessary and delivered when the production rate is increased to meet the schedule. Labour is increased accordingly to support the higher production rate.		
Risk Responses:			
More details:	CMS-doc-13481		

RT-402-2-23-D OT - Vendor is unable to produce sensors to specifications

Risk Rank:	2 (Medium) **Scores:** Probability : 1 (VL) ; Cost: 3 (H) Schedule: 3 (H))		**Risk Status:**	Open	
Summary:	If vendor is unable to produce sensors that meet CMS Specification then the additonal cost and delay of identifying a new vendor jeopardizes the timely and on-budget completion of the project				
Risk Type:	Threat		**Owner:**	Ulrich Heintz	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	External Risk / Vendors	
Probability (P):	5%		**Technical Impact:**	3 (H) - extremely substandard or KPP in jeopardy	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 210 k$		Minimum	= 6 months
	Most likely	= 315 k$		Most likely	= 9 months
	Maximum	= 2720 k$		Maximum	= 12 months
	Mean	= 1082 k$		Mean	= 9 months
	P * <Impact>	= 54 k$		P * <Impact>	= 0.5 months
Basis of Estimate:	If the selected vendor is unable to produce sensors to specifications a new vendor has to be developed. At a minimum this will require another preproduction run (6 month delay). At a maximum one to two prototype runs may also be required (12 months delay). The burn rate for the entire Outer Tracker is $70k/month (CMS-doc-13481). We assume half of the OT scope is impacted by a delay from this risk, thereby incurring a burn rate of $35k/month. **Min impact** = no direct cost increase. Burn rate = 6 *$35k = $210k. **Likely impact**: cost increase is covered by the 30% sensor estimate uncertainty.Burn rate = 9 *$35k = $315k. **Max impact**: the worst case scenario based on informal cost information received during the market survey is an increase in the cost of the sensors by 2/3 = 66%. 30% are covered by the cost uncertainty. The additional cost of 36% of the $6.5M sensor purchase is $2.3M.Burn rate = 12 *$35k = $420k. Total = $2,720k. We have identified a vendor (HPK) who has already produced sensors of all types that satisfy our specifications. Together with the historically reliable performance of HPK it is very unlikely that this threat will occur. We are not aware that HPK has ever failed to produce sensors to specifications after a purchase was negotiated. Hence the probability is considered to be low.				
Cause or Trigger:	Sensors delivered by vendor are substandard and vendor is unable to fix the problem.		**Impacted Activities:**	Sensor production and QC. Cost risk is implemente as a single risk. Schedule risk is implemented as three seperate risks (probability depends on senso type). There are three risk hooks for the three sensor types, but because 2S and PS-s are similar, would split the probability: 1% for PS-s (hook A), 2% for 2S (hook C), 2% for PS-p (hook B). Note: PR does not support fractions of percent.	
Start date:	1/Apr/2020		**End date:**	3/Dec/2024	
Risk Mitigations:	CERN is carrying out a market survey to identify possible vendors. Companies are selected based on their capability to produce sensors that satisfy CMS specifications and to produce all the sensors needed by CMS and ATLAS within a two-year period. Companies have to be qualified by producing prototype sensors tc CMS specifications. This minimizes the probability that the selected company cannot deliver the order.				
Risk Responses:	A new vendor has to be identified and production restarted.				
More details:	CMS-doc-13481				

RT-402-2-24-D OT - Problem with module mechanical parts vendor

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 2 (M) Schedule: 2 (M))		**Risk Status:**	Open	
Summary:	Major problems with the vendor of mechanical (bridges, spacers, etc) parts for modules				
Risk Type:	Threat		**Owner:**	Leonard G Spiegel	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**		
Probability (P):	20%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 0 k$		Minimum	= 0 months
	Most likely	= 0 k$		Most likely	= 0 months
	Maximum	= 324 k$		Maximum	= 6 months
	Mean	= 108 k$		Mean	= 2 months
	P * <Impact>	= 22 k$		P * <Impact>	= 0.4 months
Basis of Estimate:	Minimum impact: no extra cost nor delay Maximum impact: significant delays causing a standing army cost of $324k (54k/month module assembly labor burn rate for 6 months). The burn rate is assumed to be 1/3 times the total module assembly labor cost of 5M during the production divided by the production interval of 31 months. The 1/3 assumes that a certain fraction of the labor force is either matrixed out to other areas or can advance some of the other activities while waiting for parts.				
Cause or Trigger:			**Impacted Activities:**	Implemented as a delay between batch 3 and 4 of AL- CF spacer production for 2S (A) and PS (B), probability should be split between the two.	
Start date:	1/Apr/2020		**End date:**	31/Dec/2024	
Risk Mitigations:	Vendor qualification will provide some experience with reliability, and the contract will include schedule expectations.				
Risk Responses:	Increased resources for labor and infrastructure to parallelize downstream activities in Module Assembly and Plank/Layer Assembly to recoup delays				
More details:	CMS-doc-13481				

RT-402-2-25-D OT - Module assembly yield is low

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 1 (L) Schedule: 2 (M))		**Risk Status:**	Open	
Summary:	If the yield from Module Assembly is lower than expected, then the additional resources needed to compensate jeopardize project schedule and budget				
Risk Type:	Threat		**Owner:**	Leonard G Spiegel	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**		
Probability (P):	10%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 0 k$		Minimum	= 0 months
	Most likely	= 40 k$		Most likely	= 0 months
	Maximum	= 240 k$		Maximum	= 6 months
	Mean	= 93 k$		Mean	= 2 months
	P * <Impact>	= 9 k$		P * <Impact>	= 0.2 months
Basis of Estimate:	Minimum: no cost impact, no delay. Likely: no delay. 40k$ is the cost of additional labour and additional components. Maximum: 240k$ is the cost of additional labour and additional components. 6 month delay: time to diagnose the problem and improve the module assembly procedure.				
Cause or Trigger:			**Impacted Activities:**	Implemented as a Risk Hook between completion of 2S/PS Modules Batch 3 (assuming that is when you assess the yield) and Mechanical Assembly of Batch 5 (Batch 4 is in progress). Share probability equally between PS (hook A) and 2S (hook B).	
Start date:	1/Apr/2020		**End date:**	31/Dec/2024	
Risk Mitigations:	Extensive prototyping should mitigate the risk of overestimated yields in Module assembly.				
Risk Responses:	Additional resources both to compensate for the lower yield and further parallelize the assembly procedure to regain schedule would be needed				
More details:	CMS-doc-13481				

RT-402-2-33-D OT - More preproduction modules needed

Risk Rank:	2 (Medium) **Scores:** Probability : 3 (M) ; Cost: 2 (M) Schedule: 2 (M))		**Risk Status:**	Open	
Summary:	If more pre-production modules are needed to qualify the production components and assembly, then there may be cost increases and delays.				
Risk Type:	Threat		**Owner:**	Meenakshi Narain	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**		
Probability (P):	25%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 0 k$		Minimum	= 0 months
	Most likely	= 0 k$		Most likely	= 0 months
	Maximum	= 330 k$		Maximum	= 6 months
	Mean	= 110 k$		Mean	= 2 months
	P * <Impact>	= 28 k$		P * <Impact>	= 0.5 months
Basis of Estimate:	Additional labour: 22k/month and additional mechanical components 10k/month. Total = 6 months * ($22k + $10k) = $192k. The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). Total max impact = $192k + 6 * $23k = $330k.				
Cause or Trigger:			**Impacted Activities:**	Module preproduction activities would stretch an additional 3 months. Implemented as a hooks between 2S (hook B) or PS (hook A) Preproduction Module Assembly activities complete and 2S/PS Ready for production. Share probability equally.	
Start date:	1/Apr/2020		**End date:**	31/Dec/2020	
Risk Mitigations:	Preproduction activities are adequately estimated assuming no major problems arise, after extensive prototyping				
Risk Responses:					
More details:	CMS-doc-13481				

RT-402-2-35-D OT - Temporary loss of module assembly facility

Risk Rank:	2 (Medium) **Scores:** Probability : 4 (H) ; Cost: 1 (L) Schedule: 1 (L))	**Risk Status:**	Open
Summary:	If a Module Assembly facility temporarily becomes inoperable due to loss of critical equipment or Act of God, then the resultant dip in module throughput may jeopardize timely completion of the project		
Risk Type:	Threat	**Owner:**	Meenakshi Narain
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	
Probability (P):	50%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 1-point - single value Minimum = k$ Most likely = 50 k$ Maximum = k$ Mean = 50 k$ P * <Impact> = 25 k$	**Schedule Impact:**	PDF = 1-point - single value Minimum = months Most likely = 1 months Maximum = months Mean = 1 months P * <Impact> = 0.5 months
Basis of Estimate:	It is assumed that in 1 month the equipment would be replaced and assembly could then proceed at the affected site. Risk impact is estimated from 1/2 of the module labor burn rate ($84k/month) plus an estimate of $8k to make emergency repairs.		
Cause or Trigger:		**Impacted Activities:**	All assembly activities at the affected site. Imjplemented as a hook between PS/2S mechanical assembly of subsequent batches (note those should be correlated - if you cannot build PS, you also cannot build 2S) at Fermilab (B,D) and Brown (A,C)
Start date:	1/Apr/2020	**End date:**	31/Dec/2024
Risk Mitigations:	Having two sites is already a hedge against the complete stoppage of module production, and should one site become temporarily inoperable, components could be redirected to the other site temporarily to mitigate the impact		
Risk Responses:	Module components can be diverted to the unaffected site to utilize its full throughput, and additional resources added to increase module production throughput at both sites (once the affected one is re-established) to regain time in the schedule		
More details:	CMS-doc-13481		

RT-402-2-43-D OT - Problem with carbon fiber vendor

Risk Rank:	2 (Medium) **Scores:** Probability : 3 (M) ; Cost: 1 (L) Schedule: 2 (M))	**Risk Status:**	Open
Summary:	If there is a problem with the Carbon Fiber vendor then there could be delays or cost increases. Examples of problems include: vendor going out of business, vendor delivering substandard CF, or the vendor cannot deliver according to the agreed schedule.		
Risk Type:	Threat	**Owner:**	Stefan Gruenendahl
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	External Risk / Vendors
Probability (P):	25%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = 23 k$ Most likely = 79 k$ Maximum = 158 k$ Mean = 87 k$ P * <Impact> = 22 k$	**Schedule Impact:**	PDF = 3-point - triangular Minimum = 1 months Most likely = 3 months Maximum = 6 months Mean = 3.33 months P * <Impact> = 0.8 months
Basis of Estimate:	Minimum impact: the problem is relatively modest and is solved by the vendor within 1 months without any direct cost impact to the project. Likely impacts: the problem is more significant and requires additional prototypes with the vendor resulting in a delay of 3 months and a cost of $10k for CF and machining. Maximum impact: if we need to switch vendor we would need to qualify a scond vendor resulting in a 6 month delay. The cost increase could be $20k for prototyping and setup costs with the new vendor. The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). Min cost = $0k + 1month * $23k burn rate = $23k. Likely cost = $10k + 3month * $23k burn rate = $79k. Max cost = $20k + 6months * $23k burn rate = $158k.		
Cause or Trigger:		**Impacted Activities:**	Carbon fiber based structures in both module mechanics and flat barrel mechanics. Implemented as a delay in procurement for production planks (hook A) and spacers (hook B).
Start date:	1/Jan/2019	**End date:**	31/Dec/2024
Risk Mitigations:	Prototyping experience in the next two years should result in a reliable cost estimate of the necessary carbon fiber for both module and flat barrel structures.		
Risk Responses:			
More details:	CMS-doc-13481		

RT-402-2-46-D OT - Problem with carbon foam vendor

Risk Rank:	3 (High) **Scores:** Probability : 3 (M) ; Cost: 2 (M) Schedule: 3 (H))		**Risk Status:**	Open	
Summary:	If there is a problem with the Carbon Foam vendor then there could be delays or cost increases. Examples of problems include: vendor going out of business, vendor delivering substandard Carbon Foam, or the vendor cannot deliver according to the agreed schedule.				
Risk Type:	Threat		**Owner:**	Stefan Gruenendahl	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	External Risk / Vendors	
Probability (P):	25%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 23 k$		Minimum	= 1 months
	Most likely	= 158 k$		Most likely	= 6 months
	Maximum	= 396 k$		Maximum	= 12 months
	Mean	= 192 k$		Mean	= 6.33 months
	P * <Impact>	= 48 k$		P * <Impact>	= 1.6 months
Basis of Estimate:	The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). Minimum impact: the problem is relatively modest and is solved by the vendor within 1 months without any direct cost impact to the project. Cost impact = 1 month * $23k/month (burn rate). Likely impacts: the problem is more significant and requires additional prototypes with the vendor resulting in a delay of 6 months and a cost of $20k for Carbon Foam and technical work. Total likely impact = $20k + 6 * $23k = $158k. Maximum impact: if we need to switch vendor we would need to qualify a second vendor resulting in a 12 month delay. The cost increase could be $120k for increased vendor costs, prototyping and setup costs with the new vendor.Total likely impact = $120k + 12 * $23k = $396k.				
Cause or Trigger:			**Impacted Activities:**	Fabrication of the carbon foam structures in Mechanics - implemented as a delay in the carbon foam procurement for production planks.	
Start date:	1/Jan/2019		**End date:**	31/Dec/2024	
Risk Mitigations:					
Risk Responses:	Join with the rest of the LHC community in seeking out a new vendor of Carbon Foam				
More details:	CMS-doc-13481				

RT-402-2-54-D OT - Mechanics materials degraded by radiation

Risk Rank:	2 (Medium) **Scores:** Probability : 2 (L) ; Cost: 1 (L) Schedule: 1 (L))		**Risk Status:**	Open	
Summary:	If the mechanical materials are susceptible to integrity degradation due to radiation exposure, the resulting material modifications and design changes jeopardize timely completion of the flat barrel.				
Risk Type:	Threat		**Owner:**	Stefan Gruenendahl	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	Technical Risk / Quality	
Probability (P):	10%		**Technical Impact:**	2 (M) - significantly substandard	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 48 k$		Minimum	= 1 months
	Most likely	= 96 k$		Most likely	= 2 months
	Maximum	= 144 k$		Maximum	= 3 months
	Mean	= 96 k$		Mean	= 2 months
	P * <Impact>	= 10 k$		P * <Impact>	= 0.2 months
Basis of Estimate:	Total cost of the materials involved is about $300k (MandS) and $220k in labor to make the production planks (x80) and rings (x6). It is assumed that any problems are found early in the mechanics production such that the likely cost impact is about 10 of the MandS and labor: min/likely/max 25/50/75 k$ and a delay of 1/2/3 months. The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). Min cost = $25k + 1months * $23k burn rate = $48k. Likely cost = $50k + 2month * $23k burn rate = $96k. Max cost = $75k + 3months * $23k burn rate = $144k.				
Cause or Trigger:			**Impacted Activities:**	Plank and ring fabrication would be delayed.	
Start date:	1/Jan/2019		**End date:**	1/Apr/2021	
Risk Mitigations:	All materials and assemblies will be radiation tested in the prototyping phase				
Risk Responses:					
More details:	CMS-doc-13481				

RT-402-2-57-D OT - Major failure of layer assembly infrastructure

Risk Rank:	1 (Low) **Scores:** Probability : 1 (VL) ; Cost: 1 (L) Schedule: 2 (M))	**Risk Status:**	Open
Summary:	If there is a longer term non-availability of FNAL CO2 system, survey/alignment equipment, autoclave/oven, etc, then the subsequent delay until a alternative is in operation jeopardizes timely completion of the flat barrel		
Risk Type:	Threat	**Owner:**	Stefan Gruenendahl
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	External Risk / Facilities
Probability (P):	5%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = 56 k$ Most likely = 112 k$ Maximum = 178 k$ Mean = 115 k$ P * <Impact> = 6 k$	**Schedule Impact:**	PDF = 3-point - triangular Minimum = 2 months Most likely = 4 months Maximum = 6 months Mean = 4 months P * <Impact> = 0.2 months
Basis of Estimate:	Estimate we need min/likely/max = 2/4/6 months to complete repairs or procure replacement at a cost of min/likely/max = 10/20/30k$. The L3 burn rate due to the delay of downstream activities is $23k/month (CMS-doc-13481). Min cost = $10k + 2months * $23k burn rate = $56k. Likely cost = $20k + 4month * $23k burn rate = $112k. Max cost = $40k + 6months * $23k burn rate = $178k.		
Cause or Trigger:	major component failure (e.g. pump, accumulator)	**Impacted Activities:**	Implemented as three risk hooks, one each for Inner (hook A), Middle (hook B), and Outer (hook c) Layer assembly, delay between start milestone and actual assembly. Suggest splitting the probability equally.
Start date:	13/Jun/2017	**End date:**	31/Dec/2025
Risk Mitigations:	monitor system performance & perform regular maintenance		
Risk Responses:	repair system; buy replacement (mobile) system		
More details:	CMS-doc-13481		

RT-402-2-58-D OT - Damage to Flat Barrel Planks

Risk Rank:	2 (Medium) **Scores:** Probability : 1 (VL) ; Cost: 1 (L) Schedule: 1 (L))		**Risk Status:**	Open	
Summary:	If an accident damages a flat barrel component (e.g. a plank or an end ring) then repair work would cause a delay and cost increase. The damage could be purely physical (e.g. the components are crushed), chemical (e.g. water contamination), or other hazard.				
Risk Type:	Threat		**Owner:**	Stefan Gruenendahl	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	Management Risk / Logistics	
Probability (P):	5%		**Technical Impact:**	3 (H) - extremely substandard or KPP in jeopardy	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 30 k$		Minimum	= 1 months
	Most likely	= 91 k$		Most likely	= 1 months
	Maximum	= 141 k$		Maximum	= 2 months
	Mean	= 87 k$		Mean	= 1.33 months
	P * <Impact>	= 4 k$		P * <Impact>	= 0.1 months
Basis of Estimate:	Minimum Impact: the physical damage is not permanent and only rework is needed to effect a repair. The estimated delay is 1 month at a cost of 2 FTE-months of engineering or about $30k. Min impact total = $30k. Likely impact: One entire Layer 2 plank (plus associated modules) needs to be replaced including about 11 modules maximum (11 * $5k = $55k). To this is added the mechanics cost and labor (about 10 hours per plank) for a total of about $6k. The delay is 1 month (assuming that modules are available). Likely impact total = $30k +$55k + $6k = $91k. Maximum impact: the damage is catastrophic for a Layer 3 plank,including about 15 modules (15 * $5k = $75k). To this is added the mechanics cost and labor (about 10 hours per plank) for a total of about $6k. The delay is 2 month (assuming that modules are available). Likely impact total = $60k +$75k + $6k = $141k. The risk occurs late in the schedule and hence does not have a significant burn rate from escalation. The standing army costs (they are not idle!) are included in the labor costs above.				
Cause or Trigger:	Damage to a plank during plank assembly or during layer assembly or transport.		**Impacted Activities:**	Implemented as a delay between QC testing of Inner, Middle, and Outer Layer (whichever is last) and milestone of completion of Flat Barre	
Start date:	1/Jan/2021		**End date:**	31/Dec/2024	
Risk Mitigations:	Plank handling procedures are designed to reduce damage due to handling. Transport enclosures are desgined to minimize risk to detector.				
Risk Responses:	The damaged plank would need to be replaced, increasing both time and labor depending on the extent of the damage				
More details:	CMS-doc-13481				

RT-402-2-59-D OT - Damage to Flat Barrel Layer

Risk Rank:	2 (Medium) **Scores:** Probability : 1 (VL) ; Cost: 3 (H) Schedule: 3 (H))		**Risk Status:**	Open	
Summary:	If an accident destroys a major flat barrel component (i.e. a whole layer) then repair work would cause a delay and cost increase. The damage could be purely physical (e.g. the components are crushed), chemical (e.g. water contamination), or other hazard.				
Risk Type:	Threat		**Owner:**	Stefan Gruenendahl	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**		
Probability (P):	1%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 3-point - triangular	**Schedule Impact:**	PDF	= 3-point - triangular
	Minimum	= 930 k$		Minimum	= 6 months
	Most likely	= 1880 k$		Most likely	= 9 months
	Maximum	= 3150 k$		Maximum	= 12 months
	Mean	= 1987 k$		Mean	= 9 months
	P * <Impact>	= 20 k$		P * <Impact>	= 0.1 months
Basis of Estimate:	Cost to rebuild an entire layer using planks at $6k labor per plank and modules at $5k/module, for either Layer 1 (minimal risk), Layer 2 (likely risk or Layer 3 (maximum risk). The cost to replace the modules for Layer 3 (assuming the total number of spares needed by CMS remains the same) = 540 * $5k = $2.7M (including M&S and module assembly labor). The cost for the mechanics of a layer is about $ 150 k (1/3 of the total). Labor cost estimate (plank construction + module mounting) ranges from 200k$ (layer 1) to 400k$ (layer 3) or $300k on average. Maximum direct cost impact = $3.15M$. Layers 1 and 2 scaled accordingly.				
Cause or Trigger:	catastrophic damage to a majority of components of a Flat Barrel layer.		**Impacted Activities:**	Implemented as a delay between QC testing of Inner, Middle, and Outer Layer (whichever is last) and milestone of completion of Flat Barre	
Start date:	1/Jan/2021		**End date:**	31/Dec/2024	
Risk Mitigations:	Design and enforcement of Flat Barrel handling and transport procedures, and design of Flat Barrel layer tranport enclosures.				
Risk Responses:	rebuild planks using spare modules, and reassemble layer.				
More details:					

RT-402-2-60-D OT - Problems with wire bonding

Risk Rank:	2 (Medium) **Scores:** Probability : 5 (VH) ; Cost: 1 (L) Schedule: 1 (L))		**Risk Status:**	Open	
Summary:	Temporary loss of a bonding machine at FNAL, Princeton, or Rutgers. While the repair costs are covered there would be additional expenses in the hold-up of module assembly until the machine is repaired or the work load could be rebalance.				
Risk Type:	Threat		**Owner:**	Leonard G Spiegel	
WBS:	402.2 OT - Outer Tracker		**Risk Area:**	Technical Risk / Reliability or Performance	
Probability (P):	80%		**Technical Impact:**	0 (N) - negligible technical impact	
Cost Impact:	PDF	= 2-point - flat range	**Schedule Impact:**	PDF	= 2-point - flat range
	Minimum	= 13.5 k$		Minimum	= 1 months
	Most likely	= k$		Most likely	= months
	Maximum	= 27 k$		Maximum	= 2 months
	Mean	= 20 k$		Mean	= 1.5 months
	P * <Impact>	= 16 k$		P * <Impact>	= 1.2 months
Basis of Estimate:	Probability is assumed to be 20% per machine (four machines: two at FNAL, one at Princeton, one at Rutgers) so roughly 80% probability in total (the number that is used in risk ranking). In the MC the probability is treated as 4 independent events each with P=20%. Based on a Module Assembly monthly labor burn rate of $54k and the assumption that a single wire bonder fails over the course of the production period, thus affecting 1/4 of the module assembly (burn rate = $54k/4 = $13.5k per month). This is modeled as a delay of 1-2 months in wirebonding at each of 3 sites independently, both for PS and 2S modules (correlated).				
Cause or Trigger:	Failure of a wire bonder, for example from the crash of a bonding head.		**Impacted Activities:**	Wire bonding and all OT module assembly activities that are downstream of bonding.In the MC the probability is treated as 4 independent risk events with P=20% each -- one per bonding machine.	
Start date:	20/Dec/2021		**End date:**	2/Aug/2024	
Risk Mitigations:	With time the bonding load can be rebalanced amongst the 3 bonding facilities. It may be possible to pay for expedited service from the bonding machine vendors.				
Risk Responses:	Understand how quickly a machine can be brought back into service.				
More details:					

RT-402-2-90-D OT - Key Outer Tracker personnel need to be replaced

Risk Rank:	2 (Medium) **Scores:** Probability : 3 (M) ; Cost: 2 (M) Schedule: 1 (L))	**Risk Status:**	Open
Summary:	Key engineer or senior technician with special knowledge leaves the project and needs to be replaced. If the transition can be managed such that the incoming and outgoing personnel overlap and exchange knowledge, then there is mainly a labor cost impact. If the transition is more abrupt, then there is no cost impact of overlapping personnel but there can be a delay to the project activities as the incoming person gets fully up to speed. This risk does not include the risk of losing ke managers because the project ensures that each manager has a well-trained deputy.		
Risk Type:	Threat	**Owner:**	Steven C. Nahn
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	Management Risk / Funding or Resources
Probability (P):	25%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = 75 k$ Most likely = 225 k$ Maximum = 570 k$ Mean = 290 k$ P * <Impact> = 73 k$	**Schedule Impact:**	PDF = 3-point - triangular Minimum = 0 months Most likely = 0 months Maximum = 3 months Mean = 1 months P * <Impact> = 0.3 months
Basis of Estimate:	his L2 area has 5 senior technical staff whose functions are particularly hard to replace on a short timescale by existing team members: 4 senior engineers and 1 senior technician. Experience in the CMS Phase 1 Upgrade project suggests the probability per key person is roughly 25% (probability they leave during the entire project). Some input numbers to the cost impact analysis: -- Labor cost per person = $15k/month (fully burdened senior enginer = $185k/year). -- Average burn rate per L3 area is = $23k/month (CMS-doc-13481). **Minimum scenerio**: person leaving is replaced by an existing skilled person in the team. 1 month of full overlap costing $15k of labor. No schedule delay. **Likely scenario**: person leaving is replaced by a person less familiar with the specific work. 3 months managed overlap of the outgoing and incoming people costs 3 * $15k = $45k of labor. No schedule delay. **Maximum scenario**: person leaves unexpectedly with no transfer of knowledge. It takes about 6 months to find a new person and get them fully up to speed. There is loss of productivity during this difficult transition period resulting in a net 3 month delay to L3 activities. Cost of ramp-up effort of the new person (learning but not fully contributing to deliverables) =3 FTE-months * $15k = $45k. The burn rate cost is 3 * $23k = $69k. Total cost impact = $114k Total for 5 persons: Min/Likely/Max cost impact = 5 * $(15/45/114)k = $(75/225/570)$.		
Cause or Trigger:		**Impacted Activities:**	Each key persons is independently modeled in the MC (each at P=25% and with corresponding share of the total cost impact). Typically hook the risk to the persons main activity during the production phase (maximum consequences).
Start date:	1/Jan/2018	**End date:**	
Risk Mitigations:	A number of engineers and technicians have overlapping skills, both within a given institute and across US-CMS institutes. This provides some backup in case of non-availability of a key person. Pro-active cross-training of engineers and technicians helps ensure key skills are not completely lost if a key person is no longer available.		
Risk Responses:	Aim for outgoing and incoming personnel to overlap if possible to ensure a smooth transition. Hire from skilled members of the team if appropriate. Interim suppo may be possible using engineers or technicains from elsewhere in the institute or project.		
More details:	CMS-doc-13481		

RT-402-2-91-D OT - Shortfall in Outer Tracker scientific labor

Risk Rank:	3 (High) **Scores:** Probability : 3 (M) ; Cost: 3 (H) Schedule: 0 (N))	**Risk Status:**	Open
Summary:	If a significant amount of the (uncosted) scientific labor is unavailable, then the project would then need to fund additional (costed) personnel to perform the work. It is assumed that the risk is triggered by a seriously unfavorable overall base program funding situation.		
Risk Type:	Threat	**Owner:**	Steven C. Nahn
WBS:	402.2 OT - Outer Tracker	**Risk Area:**	Management Risk / Funding or Resources
Probability (P):	30%	**Technical Impact:**	0 (N) - negligible technical impact

Cost Impact:		**Schedule Impact:**	
PDF	= 3-point - triangular	PDF	= 1-point - single value
Minimum	= 0 k$	Minimum	= months
Most likely	= 0 k$	Most likely	= 0 months
Maximum	= 1049 k$	Maximum	= months
Mean	= 350 k$	Mean	= 0 months
P * <Impact>	= 105 k$	P * <Impact>	= 0.0 months

Basis of Estimate:

In the past US-CMS has not experienced a significant lack of scientific labor (postdocs and graduate students). When shortfalls occured they were usually resolved by collaborators at US-CMS institutes or sometimes from iCMS.

We assign a 30% probability that a significant shortfall occurs in future, due to unfavorable funding conditions in the base program.

The contributed labor for the scope of this L2 area is 60.8 FTE-years spread over about 5 years. This does not includethe more secure L2 and L3 managers who are tenuredfaculty and senior Fermilab scientists.

We estimate the loss could be up to 20% of the total contributed labor or 12.2 FTE-years (e.g. this is a loss of 50% of all contributed labor for a two year period or a loss of 1/3 of the contributed labor for 3 years).

The missing labor could be replaced by costed personnel: a mixture of mid-range technicians, junior technicians, or undergraduates costing respectively 62$/hr, 50$/hr and 18$/hr fully-burdened (43$/hour on average). Allowing for four years of escalation at 3.1% per annum yields an average cost of 49$/hr or 86k$/FTE-year (1768hrs worked per year).

The (min/likely/max) cost impact is therefore: 86k$ per FTE-year * (0/0/12.2) FTE-years = $(0/0/1049)k.

Cause or Trigger:	The risk is triggered by an unfavorable base program funding situation.	**Impacted Activities:**	
Start date:	1/Oct/2018	**End date:**	
Risk Mitigations:	Work with institutes and agencies to ensure the anticipated amount of scientific labor will be available. Where shortfalls look likely to occur, seek alternatives amongst other US-CMS institutes or even from iCMS institutes.		
Risk Responses:	Seek replacement scientific labor in other institutes. If this labor cannot be found then contingency will need to be spent to supplement the effort with costed labor (e.g. technicians).		
More details:	CMS-doc-13509 (FTE data at CD1)		