1 2021_09_01 - Leo Greiner - DRAFT
2 EIC hybrid detector cost estimate - (same as all-silicon with outer barrel layers removed and implications propagated through the rest of the estmate)
3 First pass for a cost estimate for the all-silicon EIC detector concept. Note that the costs are broken out into detector components to allow for easy addition/removal of all-silicon components for modification. The costing of the silicon and modulization is at the end and will need to be made as pa
4 No overhead or yearly escalation in materials costs.
5 All flex PCBs in the staves and discs are Aluminum conductor available at the CERN PCB shop.
6 Most of the estimates come from engineering judgement
7 Not all procurement numbers are fully vetted, "*" in verify/scrub column needs checking
8 Assumes CMM available at assembly sites (add ~150k per site if not)
9 Silicon costs are separate from layer/disc assembly and have it's own WBS. Scale with area
10 Signal multiplexing boards are in the services WBS
11 This WBS ends with an assembeled and tested detector in BNL. Installation and testing is another set of tasks not in ths estimate.
12 Places where one would wish to run parallel assembly sites are marked with yellow. The full effort is included, tooling and machinery will need to be multiplied by the number of assembly sites. See comments

	WBS	task	Mech engineer (days)	Mech Technician (days)	Electrical Engineer (days)	Electrical Technician (days)	Postdoc (instrumentation) (days)	student (days)	staff (days)	material ($k)	comments	verify/scrub
13												
15		**staves**									assumes ITS-2 like truss staves and ITS-3 like bent silicon	
16		**vertexing layers**										
17		carbon foam design	10	2					5		most of this is a modification of ITS-3 design, hours reflect that	
18		support shell design	10	2					5			
19		test and iteration	8	5			5		5	3		
20		fabricate carbon foam	5	10			5		2	5		
21		fabricate support shell	5	10			5		2	5		
22		stave transition pieces/bypass capacitor assembly design	10	3	15	3	5		5	1		
23		test fab and iteration	8	8	10	8	5	10	5	5	$2k PCB layout, fabricate test PCBs $2k, 3d printing of parts $2k, testing material 1k	
24		stave transition pieces/bypass capacitor assembly fabricate	5	5	5	1	5	5	3	21	16 stitched sensor rows for vertexing (2 half-layers) 64 assemblies needed. Make 70 (10% spares and yield reserve) $100 for 3D printed parts, $200 per PCB (loaded), acceprance testing, QA	
25		assembly tooling design	15	5			5		5			
26		test fab and iteration	15	15			10	10	5	8	7k for tooling, $500 CFC, $500 misc	
27		assembly tooling fabricate	10	15			5		3	5	5k tooling modification	
28		silicon acceptance testing					8	4	2	7	4 hr per stitched row, $6k for ITS-3 test station, 1k for misc	
29		assembly of half layers	5	10	5	5	10		5	1	adhesives, supplies	
30		metrology	1	4					1		1 day per half layer	
31		testing	1	1	1	1	10	4			as per acceptance testing	
32												
33		**vertexing layers total**	**108**	**95**	**36**	**18**	**78**	**33**	**53**	**61**		
34												
35		**middle layers**									1.57 m^2	
36		stave mech design	25	5			5			5	procure misc parts and integrate into design	
37		stave mech tooling design	25	5						5		
38		test fab and iteration	10	25	2	2	25	10	10	18	$15k tooling, 1k CFC, 2k testing setup (bending, twist, metrology) grounding of CFC, integration into grounding plan	
39		stave mech fabrication	20	128	5	5	20	40	15	28	54 staves needed for ML, build 64 staves (6 spare, 4 for yield issues) assume 1 stave truss/day assembly and 1 day to fabricate truss parts (should run pipelined), $400 for parts	
40		cooling plate design	10	5			5		1			
41		cooling plate tooling design	15	5			2		1			
42		test fab and iteration	10	15			5	5	5	15	10k for tooling, 2k for misc, fab 2 pieces, test with metrology, tooling modify $3k	
43		cooling plate fabrication	5	32			5	5	1	6	assume 4 hr per cold plate fab and assy pipelined	
44		flex PCB design			17	2	2		2	1	schematic and layout parameters, parts selection	
45		test fab and iteration flex PCB design			10	10	5	5	5	12	6k layout, this is Al flex PCB, only available from CERN PCB shops. 3k per test piece (~1 m long), 2 test pieces	
46		fabrication flex PCB design			8	8	8	8	2	105	fabricate 70 @ 1.5k each - acceptance testing, QA	
47		stave transition pieces/bypass capacitor assembly design	10	3	15	3	5		5	1	different design from vertexing layers	
48		test fab and iteration	8	8	10	8	5	10	5	5	$2k PCB layout, fabricate test PCBs $2k, 3d printing of parts $2k, testing material 1k	
49		stave transition pieces/bypass capacitor assembly fabricate	5	5	5	1	5	5	3	21	Make 70 (10% spares and yield reserve) $100 for 3D printed parts, $200 per PCB (loaded), acceptance testing, QA	
50		assembly tooling design	25	5	5			5	5	1		
51		test fab and iteration	15	20	5	5	10	10	10	25	15k for tooling, 2k for misc, 8k for tooling mod	
52		assembly tooling fabrication	10	15	2	2	5	5	1	60	15k per station of tooling. Assume 2 stations for assembly at each site, 2 sites	
53		silicon acceptance testing			1	1	26	26	2	10	assume modules are 51 x 90 mm. We need 4 x 64 staves = 256 modules. Test 5 per day by postdoc/student. 10k for testing station	
54		assembly of staves	5	96	5	96	96	40	20	20	In pipeline, assume 3 people can assemble 1 stave in 1.5 days (glue latencies) + 10k to set up clean room assembly space @ 2 sites	
55		metrology	1	32					3	1	2 staves per day metrology	
56		testing					32	16	16		individual completed stave testing @ 2 per day	
57												
58		**middle layers total**	**199**	**404**	**90**	**143**	**266**	**190**	**112**	**339**		
59												
60		**discs**									assumes disc plates of carbond foam between face sheets	
61		**half discs 1, -1**									0.22 m^2	
62		flex PCB design			20	3	3		5		multiple flex PCB designs to cover the half disc surface, designs similar but not identical, and different sizes	
63		test fab and iteration flex PCB design			13	15	8	8	5	17	3 design layout @ 1.5k each + 2k each for fab of 2 pieces each. Testing and QA	
64		fabrication flex PCB designs			3	5	1	1	1	22	assume 3 flex PCBs per half disc @ 1.5k each with 1 spare/yield each	
65		plate design	15	3			3		3			
66		test fab and iteration plate design	2	8			5	5	5	3	2k tooling, 1k materials. layup, trim, machine, test mechanically and thermally, includes cooling (water or air)	
67		half-disc plates fabricate	2	10			3	3	3	6	need 4, make 6 (may be differences) 1k in materials each	
68		disc transition pieces/bypass capacitor assembly design	10	3	15	3	5		5	1	use ML starting point	
69		test fab and iteration	8	8	10	8	5	10	5	5	hope to use same design for all discs so only do this once. $2k PCB layout, fabricate test PCBs $2k, 3d printing of parts $2k, testing material 1k	
70		stave transition pieces/bypass capacitor assembly fabricate	1	3	1	3	3	2	1	5	need 12, fab 16. $100 for 3D printed parts, $200 per PCB (loaded), acceptance testing, QA	
71		assembly tooling design	8	3				5	5	1	small disc	
72		test fab and iteration	5	8			3	3	3	5	5k for tooling. Assembly in one location	
73		assembly tooling fabricate	2	5	1	1	2	2	2	4	3k for fix/mod, 1k incidentals	
74		assembly of modules onto disc halves	1	20	1	20	20	10	5	2	assume 1 week/half disc assembly 3 people 2k for adhesives, misc. assembly materials	
75		metrology		2							2 disc halves per day	
76		testing					2	1	1		2 disc halves per day	
77												
78		**half discs 1, -1 total**	**54**	**73**	**64**	**58**	**63**	**50**	**49**	**71**		
79												
80		**half discs 2, -2**									0.83 m^2	
81		flex PCB design			30	4	4		5		multiple flex PCB designs to cover the half disc surface, designs similar but not identical, and different sizes	
82		test fab and iteration flex PCB design			15	18	10	10	7	33	6 design layout @ 1.5k each + 2k each for fab of 2 pieces each. Testing and QA	
83		fabrication flex PCB designs			3	5	5	5	5	60	assume 6 flex PCBs per half disc (see power layout proposal) with one spare each at $2k per flex PCB 1 spare/yield each	
84		plate design	15	3			3		3			
85		test fab and iteration plate design	4	8			5	5	5	6	5k tooling, 1k materials. layup, trim, machine, test mechanically and thermally, includes cooling (water or air)	
86		half-disc plates fabricate	2	10			3	3	3	6	need 4, make 6 (may be differences) 1k in materials each	
87		stave transition pieces/bypass capacitor assembly fabricate	1	3	1	3	5	2	1	9	need 24, fab 26. $100 for 3D printed parts, $200 per PCB (loaded), acceptance testing, QA. All discs same design	
88		assembly tooling design	10	3				5	5	1	larger disc	
89		test fab and iteration	5	8			5	5	5	3	2k tooling, 1k materials. layup, trim, machine, test mechanically and thermally, includes cooling (water or air)	
90		assembly tooling fabricate	2	5	1	1	2	2	2	4	3k for fix/mod, 1k incidentals	
91		assembly of modules onto disc halves	2	40	2	40	40	20	10	2	assume 2 week/half disc assembly 3 people 2k for adhesives, misc. assembly materials	
92		metrology		2							2 disc halves per day	
93		testing					2	1	1		2 disc halves per day	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
94															
95				**half discs 2, -2 total**	**41**	**82**	**52**	**71**	**84**	**58**	**52**	**124**			
96															
97				**half disc 3, 4, 5, -3, -4, -5**										3.52 m^2	
98				flex PCB design			35	6	6		5			8 design / half disc. multiple flex PCB designs to cover the half disc surface, designs similar but not identical, and different sizes	
99				test fab and iteration flex PCB design			18	20	12	12	8	56		8 design layout @ 2k each + 3k each for fab of 2 pieces each. Testing and QA	
100				fabrication flex PCB designs			3	5	5	5	5	336		assume 8 flex PCBs per half disc (see power layout proposal). We need 12 half-discs *8 PCB designs = 96 flex PCBs. with 2 spare of each type. at $3k per flex PCB	
101				plate design	15	3			3		3			12 half plates - all same size	
102				test fab and iteration plate design	4	10			5	5	5	6		10k tooling, 2k materials. layup, trim, machine, test mechanically and thermally, includes cooling (water or air)	
103				half-disc plates fabricate	5	36	1	1	10	10	10	31		12 plates needed, make 14. 2k materials each. 3k misc adhesives, misc. 3 days/plate in production	
104				stave transition pieces/bypass capacitor assembly fabricate	1	3	1	3	5	2	1	32		need 96, fab 105. $100 for 3D printed parts, $200 per PCB (loaded), acceptance testing, QA. All discs same design	
105				assembly tooling design	15	5				5	5	1		larger disc	
106				test fab and iteration	10	15			5	5	5	3		10k tooling, 1k materials. layup, trim, machine, test mechanically and thermally, includes cooling (water or air)	
107				assembly tooling fabricate	5	10	1	1	2	2	2	20		10k for tooling x 2 assembly sites	
108				assembly of modules onto disc halves	20	270	20	180	180	100	40	16		larger job. 3 weeks/half disc assembly for 3 people. 8k materials per site	
109				metrology		12								1 disc half per day	
110				testing		12								1 half disc / day	
111															
112				**half disc 3, 4, 5, -3, -4, -5 total**	**75**	**376**	**79**	**216**	**233**	**146**	**89**	**501**			
113															
114				mechanics											
115				**mechanics for installtion and suport of discs**										assembly of disc banks comes in this WBS	
116															
117				support cones design	30				10		10			4 x half cones	
118				support cones tooling design	20	5			5		5				
119				support cones test pieces fabricate	5	15			10	5	5	30		25k tooling, 5k materials and closeouts	
120				support cones tooling design test and iteration	10	10			5	5	10	10		includes testing and 10k change to tooling	
121				support cones fabricate	3	50			10	10	10	20		4 cones 5k each materials and closeouts 2 people, 1 week per + 1 w	
122				support cylinders design	15				5		5			4 x half cylinders	
123				support cylinders tooling design	10	5			5		5				
124				support cylinders test pieces fabricate	3	10			10	10	5	20		15k tooling, 5k materials and closeouts	
125				support cylinders tooling design test and iteration	8	10			10	10	10	8		8k change to tooling	
126				support cylinders fabricate	3	60			15	15	10	20		4 cyl 5k each materials and closeouts 2 people, 1.5 week per + 1 w	
127				disc support system design	40	5			25		25				
128				disc support system test fab	5	15			15			15		clamps, supports, rails?, fastening points in cyl and cones, etc. 15k materials for mock up, tooling for positioning	
129				disc support system test and iterate	15	15			15			15			
130				disc support system fab	7	35			20	20	10	80		in all cones and cylinders, 10k per cyl/cone	
131				assembly and testing	3	15			15	15					
132				assembly of disc bank halves	20	30	5	5	30	20	20	2			
133				testing of disc bank halves				2	20	20	20	2			
134															
135				**mechanics for installtion and suport of discs total**	**197**	**280**	**5**	**7**	**225**	**130**	**150**	**222**			
136															
137				**mechanics for installtion and suport of staves**										assembly of barrel halves comes in this WBS	
138				ML end wheels and cylinder supports design	15	5	5		5		5			similar to OL => less design time	
139				ML tooling design	15	5	3		5		5				
140				ML endwheels and cylinders test fab	5	20	2	2	10	10	10	25		20k tooling, 5k materials and closeouts	
141				ML endwheels and cylinders test fab and iteration	10	15	1	1	15	10	15	8		8k tooling change	
142				ML endwheels and cylinders fab	10	100	2	2	35	10	10	20		4 pieces each, 5k materials and closeouts each 1.5 weeks half-cylinders, 1 weeks half-endwheels 2 people	
143				ML assembly and testing	3	10	3	3	10	10	10				
144				ML assembly of half-barrels	3	11	1	2	11	6	11	3		54 staves @ 5 staves/day	
145				ML testing of half barrels			1	2	11	11	11			test 5 staves/day	
146															
147				**mechanics for installtion and suport of staves total**	**61**	**166**	**18**	**12**	**102**	**57**	**77**	**56**			
148															
149				**mechanics for installtion and suport of vertexing layers**										assembly of vertexing layers comes in this WBS	
150				support cones design	25	5	5	5	5		5				
151				support cones tooling design	15	5	2	2							
152				support cones test pieces fabricate	5	15			5		5	15		10k tooling, 5k material and closeouts test 2 nested cones	
153				support cones test and iteration	10	10	2	2	10	10	10				
154				support cones fabricate	5	60			20		5	24		8 nested cones for 2 layers with services both sides	
155				assembly and testing	5	10	2	2	10	10	10	3			
156				clamshell articulation mechanism design	40	10			10		10				
157				clamshell articulation mechanism prototype	10	20	2	2	5	5	5	45		25k precision machining, 10k kinetic mounts and tooling, 10k misc	
158				clamshell articulation mechanism test	10	15			15	10	15	5		lots of measurement and motion testing	
159				iteration	15	10	1	1	5	5	5	5		rarely correct the first time	
160				clamshell articulation mechanism fabricate	10	20	2	2	5	5	5	45		complete iteration in costs	
161				assemble and test	5	10	1	1	10	10	10			same tests as last time. Measurement tooling and proceedure exists	
162				assembly of half-barrels onto mechanics	5	10	5	10	10	10	10	3			
163				testing of half barrels		2		2	8	8	8			1 half barrel/day	
164				patch panel design	5	1	2	2	3		3			should be small not many connectors	
165				patch panel fab	2	10	2	2	4	8	4	16		4 x pp services exit both sides of vertexing layers and 2 halves for the clamshell 4k each	
166															
167				**mechanics for installtion and suport of vertexing layers total**	**167**	**213**	**26**	**33**	**125**	**73**	**110**	**145**			
168															
169				**Carbon fiber**											
170				spec types/modulus	15						5				
171				procure	5							125			*
172				maintain in certification	5	24						12		0.5k/month - monitor/freezer maint, etc. 2 years. tech 1 day/month	
173															
174				**Carbon fiber total**	**25**	**24**	**0**	**0**	**0**	**0**	**5**	**137**			
175															
176				**global**										some overlap with MPGD mecanics as they will be installed together as one package	
177				main insertion rails and slides design	35	10			10		10				
178				tooling design	20	10								likely carbon many fiber pieces	
179				tooling fabricate	5	25			10		10	15		15k tooling,	
180				test pieces fabricate	5	25			5		5	7		7k materials, rollers, rails in global supports and on detector halves	
181				testing of test pieces	5	10			10	10	10	2			
182				iteration of tooling	10	5			5			8		8k tooling change	
183				Iteration of test pieces	5	20			8		8	7		as before	
184				fabrication of insertion structures	10	50			10		10	28		making at least 4 rails + roller mechanism, stops, adjustment, etc.	
185				patch panel design	20	10	5	5	5		5				
186				patch panel test fab	2	10	1	1	5	5	5	10		lots of machining, realtively close tolerances on big part	
187				patch panel test	3	5	2	2	5	5	5	5		procure connerctors, make strain relief and cable connector assessment	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
188				patch panel iteration	15	5				5		5			
189				patch panel fab	3	10			5	5	5	32		need at least 4 @ 8k each	* number of cone
190															
191				**mechanics global total**	**138**	**195**	**8**	**8**	**78**	**30**	**73**	**119**			
192															
193				**cooling system**											
194				**staves and discs**											
195				spec water cooling sytsem chiller system	10	5	5		10		10			assuming water for staves and discs, air cooling can be added later if successful. No change from all-silicon	
196				procure	2	2			2		2	25		assume 25k	*
197				design manifords, plumbing, monitoring	15	10	5	5	5		5	2			
198				test fab and iteration	10	30	3	10	10		10	20		not full system but ~20% to test full system capability	
199				fabricate manifolds, plumbing	5	40	3	15	15	15	15	30			
200				install and test	5	20	3	10	10	10	10	8			
201				integration into slow control and monitor system	2	2	5	5	15	15	15	8			
202															
203				**staves and discs cooling system total**	**49**	**109**	**24**	**45**	**67**	**40**	**67**	**93**			
204															
205				**vertexing layers**											
206				air system design and spec	25	10	10	5	20		20				
207				air system blower/chiller/conditioner spec	5		5		5		5				
208				air system blower/chiller/conditioner procure	5		5				5	160		80k for STAR PXL system 2 systems, one for testing, one installed	
209				ducting and flow control design	15		10		15		15				
210				ducting and flow control test chain fab and test	5	10	5	10	15	10	15	8		4k for 3-D printed parts, 2k flow monitor + 2k feedback control 3k misc	
211				ducting and flow control iteration	8	5	8	5	10	10	10	4		remake parts	
212				ducting and flow control fabricate	3	10	3	10	5	5	5	4		final parts	
213				assembly and testing	2	10	2	10	5	5	5	1			
214				integration into slow control and monitor system		3	3	5	10	10	10	2		2k for interfaces, etc.	
215															
216				**cooling system vertexing layers total**	**68**	**48**	**51**	**45**	**85**	**40**	**90**	**179**			
217															
218				**RDO**											
219				RDO board design			60				120			assume that we can use a lot of what was done for ITS-2/3 but will need to modify to take advantage of mulyilexing on detector to reduce services. For this WBS, assume a lot of the work can be done by an instrumentation physicist like Jo Schambach.	
220				RDO board test run fabrication			5				5	22		7k for layout fron schematic. 8k per board for 2 prototypes	
221				RDO board test			10	10	10	10	10				
222				RDO board design iteration			15	5			30	22			
223				RDO board test run fabrication										7k for layout fron schematic. 8k per board for 2 prototypes	
224				RDO board test			10	10	10	10	10				
225				RDO board fabrcication run			5	5			5	113		assuming MUX boards are successful, can reduce to ~25 (need 20) @ 4,5k each	*
226				RDO board production testing				5	5	66	10	15		3 boards a day including troubleshooting and fix. 15k for test station	
227				RDO crates design	15	5	10	5	5		5				
228				RDO crates procure	5	5	5	5			5	70		could be integration subsystem. Assume 10 crates @ 7k/crate	
229				RDO crates/system test	5	5	5	5	5		5	2		2k misc testing equiment	
230				RDO firmware and software support			100		260		260			mostly scientific staff if available. Otherwise will need to use EE	
231				install and test/fix system	10	10	10	10	15	15	15	3			
232															
233				**RDO cost total**	**35**	**25**	**235**	**60**	**310**	**101**	**480**	**247**			
234															
235				**power systems**											
236				**silicon**										assuming DC-DC converter architecture. Serial powering will be a different estimate	
237				DC-DC converters - spec			5		5		5			assuming implementation of layout (existing) onto custom PCB for installtion in EIC at stave/disc periphery	
238				DC-DC converter/components procure			5			5		88		assemble the DC-DC vonverters and other components onto the stave transition PCBs need 752 for detector. Buy 800 assume $100 each. Need $10 for additional components each	*
239				assembly of stave transition PCBs	5	5	5	10	10		10	35		assy house @ $40/board. Assume 4:1 DC-DC to PCB for assy.	
240				DC-DC converters/stave transition - hot test			5	15	10	10	5	5		5k test station	
241				spec power supplies (external rack to feed DC-DC converters)			5		5		5				
242				procure power supplies			5		5		5	189		standard 20V 1.5kW power supplies @ ~5k each (assume rad tolerant not needed) ML @ 7, 16 @ discs + 2 spare = 27	*
243				integration into slow control and monitor system			15	20	60	20	30	35		includes stave/disc control system for power enable/monitor @ ~25k to produce and 20 days EE, 15 days ET, etc $10k for slow control interfaces,	
244				install and test/fix	5	5	5	15	20	20	20	3			
245															
246				**Power system silicon total**	**10**	**10**	**50**	**60**	**115**	**55**	**80**	**355**			
247															
248				**RDO**										similar to silicon, standard power supplies for RDO	
249				LV power supply architecture design	5	5	10	5	10		5			mechanical somponent to this in feeding crates	
250				spec LV power supplies			5				5				
251				LV power supplies procure			5				5	30		5 crates, buy 6 power supplies @ ~5k each	
252				integration into slow control and monitor system			5	10	15	15	15	20		use modified silicon system	
253				set up and test/fix	2	2	5	10	10	10	10	3			
254															
255				**Power System RDO total**	**7**	**7**	**30**	**25**	**35**	**25**	**40**	**53**			
256															
257				**multiplexing boards**											
258				spec power supplies and architecture	5	5	10	5	10		5				
259				procure power supplies			5				5	15		assume 5:1 minimum reduction, need <18 boards to power => 3 power supplioes	
260				integration into slow control and monitor system			5	10	15	15	15	20		use modified silicon system	
261				set up and test/fix	2	2	5	10	10	10	10	3			
262															
263				**Power System multiplexing boards total**	**7**	**7**	**25**	**25**	**35**	**25**	**35**	**38**			
264															
265				**slow control system**										internal to silicon tracking but in overall experimental framework	
266				design slow control architecture			10		25		25				
267				procure pieces and prototype single chain			5	15	15	10	15	8		PC@ 3k, microcontroller board@1k, interfaces@2k, misc @ 2k	
268				test and design iteration			5	5	10	10	5	5			
269				procure components			5	5	5		5	22		10 controllers, 4 PCs, etc. Interfaces in the subsystem WBS	*
270				assemble system and test/fix			1	5	15	10	15	5			
271															
272				**slow control system total**	**0**	**0**	**26**	**30**	**70**	**30**	**65**	**40**			
273															
274				**database (assembly, physical configuration, run configuration and logging)**										fits into overall database for experiment. Presume realtional oracle like database.	
275				define database parameters and relations	10		10		25		10				
276				design database structure/fields	5		5		15		15				
277				integrate database into detector fabrication and assembly process	5		5		30		30			add cost of database if not already supplied by project	
278				implement and test/fix	5		5		20		20				
279															

	D	E	F	G	H	I	J	K	L	N	O
280	**database (assembly, physical configuration, run configuration and logging) total**	**25**	**0**	**25**	**0**	**90**	**0**	**75**	**0**		
281											
282	**services routing**										
283	**power cabling**									presume flex PCB from stave/disc to transition piece with DC-DC converters located there and daisy-chained to the requisite depth. cables from pp to stave/disc ends (Cu clad Al) and cables from pp to power supplies (Cu)	
284	spec cabling staves to pp	10		8		8		8			
285	spec cabling discs to pp	10		8		8		8			
286	spec cabling vertexing layers to pp	5		5		5		5			
287	spec cabling pp to PS										
288	procure samples	1		1					3		
289	test and evaluate	5	10	5	10	10		10			
290	iterate design	5		5		5					
291	procure full power cabling detector to pp	2	5	2	5	3		3	11	average 2m length @$2/m + $50 per terminated end. Need 16 for vertexing, ML = 28, discs 3,4,5)=48, discs 2 = 16, disc 1 = 8, total = 100 power wires	
292	procure full power cabling pp to PS	5		5		5		5	18	Assume that the PS are located 30m from the internal connections to the stave/disc ends. $1/meter + $50 per terminated end	*
293	test and bundle					5	5	2		4k tester,	
294											
295	**power cabling total**	**43**	**15**	**39**	**15**	**49**	**5**	**41**	**32**		
296											
297	**signal cabling**									at this point we assume the standard Samtec twinax cabling internally to multiplexing boards and fiber connections out to the RDO boards	
298	design final architecture	5		10		10		10			
299	design multiplexing boards			25		15		15			
300	fabricate multiplexing board prototype	2	2	5	10	5		5	17	5k layout, 6k per board x 2 boards	
301	MUX board firmware/software			15		40		40			
302	test			10	5	15	5	15	3		
303	iteration			15	5	15		15			
304	fabricate multiplexing boards			5	5	5		5	35	assume 10:1 multiplexing for the stave and outer 3 disc layers, assume 1:1 for vertexing and inner disc layers 10 MUX boards @ 3.5k each	
305	testing of boards			5	5	10	10	10	2		
306	procurement of samtec cables => mux boards				5	5		5	30	$75 per cable, staves = 108, discs = 286	
307	procurement of fibers => RDO boards				2	3	3	3	2	40 fibers @ $50 each	
308											
309	**signal cabling total**	**7**	**2**	**90**	**37**	**123**	**18**	**123**	**89**		
310											
311	**environmental monitoring**									could be integration subsystem but would still need to be integrated into the tracking mechanics/hardware	
312	define parameters to be monitored	5		5		10		10		temp on cooling lines, humidity, etc.	
313	define hardware that fits into experimental monitoring systems	5		5		10		10			
314	procure	2		2		7		7	10	10k for monitoring devices and interfaces	
315	install into tracking structures	2	15	2	15	10	10	10			
316											
317	**services routing environmental monitoring total**	**14**	**15**	**14**	**15**	**37**	**10**	**37**	**10**		
318											
319	**detector assembly**										
320	Detector assembly tooling design	15	5	4	4	5		5		assemble disc and stave packages before installation - cradles, clamping, etc.	
321	detector assembly tooling fabricate	5	20	5	10	10	10	10	15	15k for cradles, leveling, clamps, etc	
322	iteration and fixes	5	10	3	3	10	10	10	5		
323	detector package scaffholding and insertion cradle design	10	5			5		5		hold detector halves externally as they slide in	
324	detector package scaffholding and insertion cradle fab	5	15			5		5	20	80/20 or unistrut with rails, adjustment mechanisms, etc. large.	
325	detector assembly	5	20	5	10	15	15	15	15	1 week per side half => 4 total weeks	
326	detector cabling to patch panels	1	5	2	10	15	15	15	3	test as you go, mostly psotdoc/student/staff	
327	detector testing/fix problems	5	5	5	5	15	15	15	2	global testing	
328	detector install									tasks needed but in installtion WBS, listed here for completeness	
329	detector cable									tasks needed but in installtion WBS, listed here for completeness	
330	detector test/fix problems									tasks needed but in installtion WBS, listed here for completeness	
331	detector characterize and begin alignment with cosmic rays									tasks needed but in installtion WBS, listed here for completeness	
332											
333	**detector assembly total**	**51**	**85**	**24**	**42**	**80**	**65**	**80**	**60**		
334											
335	**silicon**										
336	**staves and discs**										
337	wafer planning			25	25	25		25			
338	mask charge								540		
339	wafers procurement			10	10	10		10	1778	assume 40% yield for stave/disc silicon. ~7k/300 mm wafer => 0.0601 m^2 per wafer. 6.1 m^2/0.4 yield (full path)/0.0601 m^2 ~ 254 wafers	*
340	thinning			60	60	60		60	254	assume processing @ 1k/wafer	*
341	dicing			60	60	60		60	126	assume 500/wafer	*
342											
343	**silicon staves and discs total**	**0**	**0**	**155**	**155**	**155**	**0**	**155**	**2698**		
344											
345	**probe testing**										*
346	probe card design	5		25		5		10			
347	probe card fabricate prototype	2	7	3	10	5		2	19	5k layout, 7k / card. 2 cards	
348	probe card testing	2	7	15	15	10		10	2		
349	iterate	2	2	10	8	10		10	1		
350	probe cards fabricate	1		3	1	2		2	45	5 probe cards, @ 7k, 5x replacement probes @2k	
351	probe machine tooling design	15		5		5		5		can be used on pick and place if that is used for probing	
352	probe testing machine spec	3		5				5			
353	probe testing machine procure	2		2				2	80	one per testing site multiply for parallelism	
354	probe test machine programming			10		15		15			
355	probe testing of wafers	2	2	2	2	13		5	2	QA chack on fab yield through wafer fab process 1/10 wafers => 25 at 2/day	
356	probe testing of dies					51	51	10		dies are stitched, Assume 20 stitched reticle objects/wafer. => 5080 "dies". @100/day	
357	shipping and transportation					5	5	5	6	shipments of 200 dies @ $200 each	
358											
359	**silicon staves and discs probe testing**	**34**	**18**	**80**	**36**	**121**	**56**	**81**	**155**		
360											
361	**vertexing layers**										
362	wafer planning			30		10		30			
363	wafers procurement			10	10	10		10	840	assume 10% yield. Need 8 wafers for outer layer, 4 for inner.Total wafers needed is 120	*
364	thinning			5	5	10		10	120	assume processing @ 1k/wafer	
365	dicing			5	5	10		10	60	assume 500/wafer	
366	shipping and transportation					5		5	5	large dies, special handling, special boxes => 5k	
367											
368	**silicon vertexing layers total**	**0**	**0**	**50**	**20**	**45**	**0**	**65**	**1025**		
369											
370	**probe testing**										
371	probe card design	5	5	10	10					assume we can use the ITS-3 probe test card design - minor mods if necessary	
372	probe card fabricate	1	1	5	5	5		5	12	2 probe cards * 7k each	
373	probe machine tooling fabricate	5	5	2	5	5		5	5	assume we can use the ITS-3 probe test tooling	
374	probe testing machine procure	5		5					80	if needed at probe testing site - may already have	
375	probe test machine programming	3	3	5	5	5		5		assume we can use the ITS-3 probe test programming	
376	probe testing of stitched dies	1	1	5	5	5	5	5	1	assume 1 week for all	
377	shipping and transportation	2	2	1	1	5	5	5	6	custom padded boxes @ 1k each, 4 boxes, 2k for transport	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
378															
379				**vertexing layers probe testing total**	**22**	**17**	**33**	**31**	**25**	**10**	**25**	**104**			
380															
381				**modules (staves and discs)**										assumes that modules are assembeled at institutiona around the world and assembeled into staves and discs. The costing for the modules is here, the costing for assembly is in the individual detector component section. ALICE ITS did 10 14-sensor modules per week per assembly machine pipelined	
382				die carrier trays design	5	5	2	2	5		5				
383				die carrier trays fabricate	3	3	1	1	10		10	6		need many, say 50 per assy site (each die carrier holds ~20) @ $30 each	
384				custom pick and place machine	25		25		25		25	150		one per assembly site multiply for parallelism	*
385				bonding machine	2		5	5	5		5	125		one per assembly site multiply for parallelism	*
386				tooling design	20	5	5	5	10		10				
387				tooling test fab and iterate	5	15	5	5	15	5	15	15		15k - high tolerance machining	
388				tooling fabricate	5	5	1	1	5	5	5	15		one per assembly site multiply for parallelism	
389				tooling assemble and qualify	5	5	2	2	10		10	15		need uniformity among testing sites. 15k is for travel to inspect and validate assembly sites.	
390				Al FPC design			10	5	5		5				
391				test fab and iterate x 2			20	20	35	30	30	15		assume modules are silicon glued and bonded to FPCs. Al FPCs in the stave and disc WBS join the FPCs on the modules to bring power and signal of joined modules to stave/disc periphery. FPC is Al conductor and of order 5x15 cm. Make 3 per iteration test, validate, make again x2 postdoc/student/staff time for QA and validation, EE, ET manage process and fix problems. Assume $300 each FPC cost is highly dependant on FPC	
392				fab Al FPCs			10	10	15	30	15	361		complexity	*
393				asemble modules	20	602	20	602	80	80	80	5		scaling from 2300 modules, 6.14 m^2/11.74 m^2 * 2300 = 1203. we need 1203 modules. use ALICE ITS2 speed for now, we can probably go faster with faster drying adhesives… 1203 modules/10 modules per week = 200 weeks x 2 people - includes wire bonding, testing, etc.	
394				module carrier design	6	8	1	1	8		8				
395				module carriers fabricate	2	2	1		10		10	5		ITS-2 used machined aluminumn carrier plates with lids @ ~100 each, let's assume we can use plastic (antistatic) and go at $1 each after investment in a $4k mould. Neet at least 200 to keep up with shipping to assy sites	
396				shipping of silicon to assy site				10	20	20	10	10		shipping of stitched dies, assume same as for shipping of modules	
397				shipping of modules to stave/disc assy site				10	20	20	10	10		shipments of 10 modules each @ $50/shipment	
398															
399				**modules (staves and discs) total**	**98**	**650**	**108**	**679**	**278**	**190**	**253**	**732**			
400															
401				**shipping of detector components to EIC**											
402				ship staves from asy sites	5	8	1	2	13	15	5	25		custom boxes, 4/shipment 10k boxes, 1k/shipment	
403				ship disc-halves from assy sites	5	8	1	2	7	13	5	30		custom boxes, 4/shipment 10k boxes, 1k/shipment	
404				ship vertex from assy site	5	8	1	2	6	3	6	15		hand deliver using airplane seats. 2 clamshell halves. 5k each for boxes, 2.5k each for two trips	
405															
406				**shipping of detector components to EIC total**	**15**	**24**	**3**	**6**	**26**	**31**	**16**	**70**			
407															
408				**travel**										reviews, meetings, planning, personnel to BNL for assembly work	
409				trips domestic								45		assume 2 trips 3 people each year for 3 years @ 2.5k/person/trip - time is in other WBS	
410				trips foreign								90		assume 2 trips 3 people each year for 3 years @ 5k/person/trip - time is in other WBS	
411															
412				**travel total**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**135**			
413															
414															
415				**total cost for hybrid (removed OL)**	**1550**	**2940**	**1440**	**1892**	**3000**	**1468**	**2578**	**7890**			
416															